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Legal ontologies over time: A systematic mapping study

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ABSTRACT

Over the last 30 years, AI & Law has provided breakthroughs in studies involving case-based reasoning, rule-based reasoning, information retrieval and, most recently, conceptual models for knowledge representation and reasoning, known as Legal Ontologies. Ontologies have been widely used by legal practitioners, scholars, and lay people in a variety of situations, such as simulating legal actions, semantic search and indexing, and to keep up-to-date with the continual change of laws and regulations. Given the high number of legal ontologies produced, the need to summarize this research realm through a well-defined methodological procedure is urgent need. This study presents the results of a systematic mapping of the literature, aiming at categorizing legal ontologies along certain dimensions, such as purpose, level of generality, underlying legal theories, among other aspects. The reasons to carry out a systematic mapping are twofold: in addition to explaining the maturation of the area over recent decades, it helps to avoid the old problem of reinventing the wheel. Through organizing and classifying what has already been produced, it is possible to realize that the development of legal ontologies can rise to the level of reusability where prefabricated models might be coupled with new and more complex ontologies for practical law.

1. Introduction

The accelerating pace of organizational change, searches for legal harmonization, plurality and heterogeneity of juridical documents, and the peculiar nature of the legal discourse have attracted special attention to the representation of semantic legal policies in compliance with the law (Breuker, 2003). Over the past few decades, the advancement of the Semantic Web (Berners-Lee, Hendler, & Lassila, 2001) has been witnessed, providing for the creation of reusable knowledge components for cooperative autonomous services, based on shared vocabularies, the ontologies.

Ontology, at a high level of abstraction, establishes common and ideally unambiguous terminology for a domain. Being a "formal and explicit specification of a shared conceptualization" (Studer, Benjamins, & Fensel, 1998), ontological engineering is often a task commonly performed by a group of knowledge engineers. The heterogeneity of the legal domain has led to the construction of content description models of miscellaneous ontological types. Ontologies encourage legal information reuse over the web, empowering the decision-making process and promoting expert systems for lawsuit simulation.

A survey based on solid methodological principles is urgently needed in order to organize available legal ontologies into categories and study their trends over the years. A Systematic Mapping Study (SMS) is a coarse-grained secondary study carried out by raising one or more research questions. Nevertheless, rather than performing deep data analysis in order to collect and integrate evidence regarding the questions raised, mapping studies are concerned with summarizing the research more comprehensively (Petersen, Feldt, Mujtaba, & Mattsson, 2008; Petersen, Vakkalanka, & Kuzniarz, 2015). Therefore, it provides for the structuring of a research area with most cited topics and, consequently, possible gaps and incipient niches.

The ***purpose*** of the SMS presented hereafter is to investigate the literature on legal ontologies and their nuances. In particular, it aims classifying/categorizing related studies in terms of representation paradigms, levels of formalization, underlying legal

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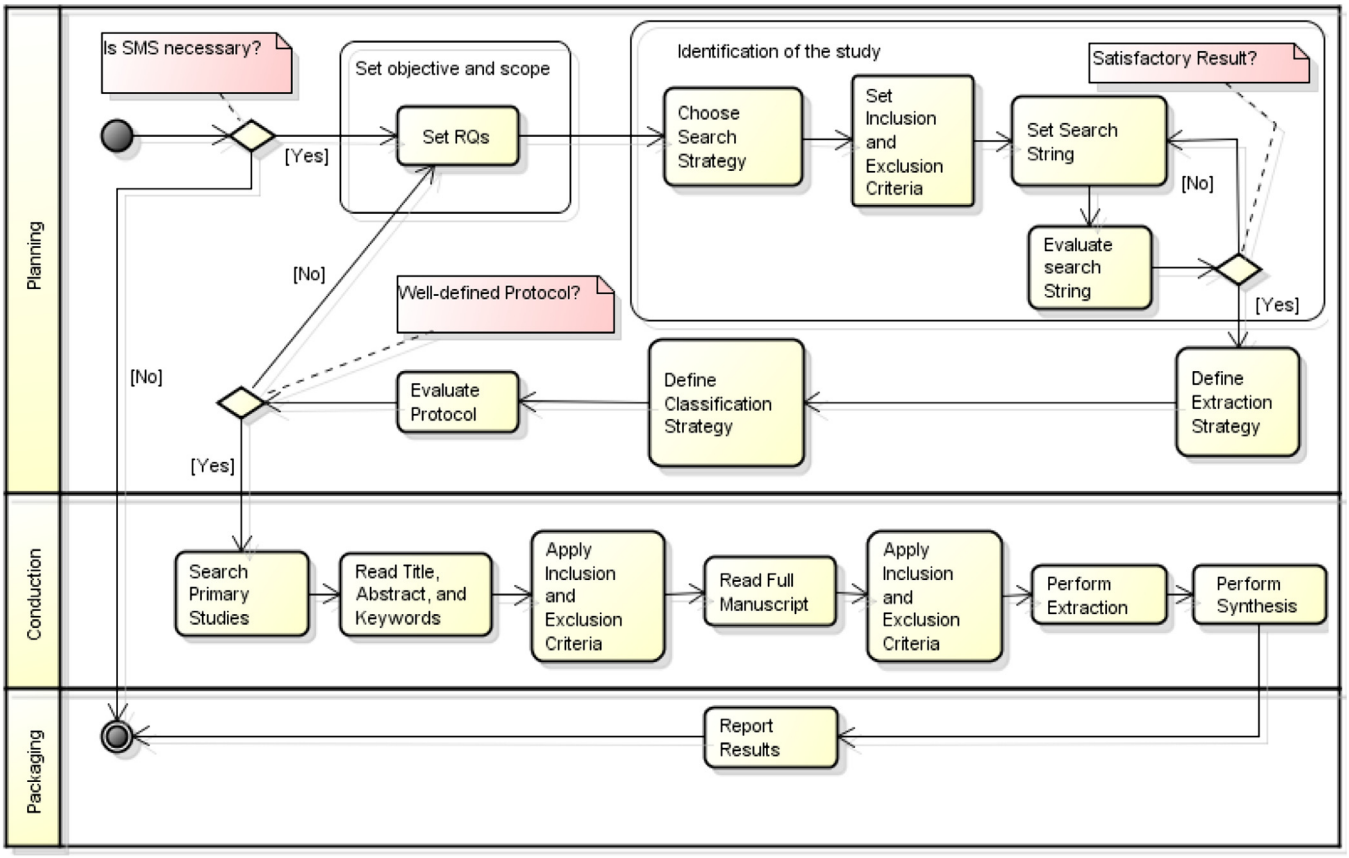

Fig. 1. The SMS Protocol. Adapted from Kitchenham and Charters (2007); Petersen et al. (2008, 2015).

theories, evaluation strategies, and semantic problems identified in the formalization of legal knowledge. Little research has been reported on the process of designing a broad mapping study for legal ontologies, based on an exhaustive search strategy. The synthesis obtained provides scores for clusters of studies, useful for deep follow-up secondary studies. In addition, as we organize these ontological foundations, new expert systems can be quickly engineered, either reusing, extending or coupling the knowledge bases already known.

The outline of the article is as follows. In Section 2, an overview of the SMS is provided, highlighting the protocol, the research questions, the search strategies, and the process for data discovery, extraction, and classification. Next, in Section 3 the primary studies discovered are highlighted, presenting answers to the research questions raised. Then, in Section 4, discussions about the data collected from the classification scheme are presented. We also argue about potential threats in conducting the mapping. Conclusion and ongoing works are presented in Section 5.

2. Protocol for the systematic mapping

A protocol is "[...] a plan that describes the conduct of a proposed systematic literature review" (Kitchenham & Charters, 2007), ensuring impartiality, control, and to some extent, replicability. Fig. 1 highlights the protocol synthesized from Kitchenham and Charters (2007) and Petersen et al. (2008), updated with new information from Petersen et al. (2015). The research methodology adopted focuses on three phases: **Planning, Conduction**, and **Packaging**. Throughout the following subsections the review planning is explored.

2.1. Research questions

During the planning phase, the following activities can be highlighted: (i) Definition of the objective and scope, (ii) Identification of the study, (iii) Definition of strategies for data extraction, and (iv) Classification of data. When defining the mapping scope, the limits of what will be researched must be defined. Therefore, the following Research Questions (RQ's) were developed:

- **RQ1**: When and where has the work been published?
- **RQ2**: What is the ontology's purpose?
- **RQ3**: Which legal theories were used?
- **RQ4**: What was the legal domain under consideration?
- **RQ5**: Which was the generalization level employed?
- **RQ6**: What engineering methodologies were applied?
- **RQ7**: What evaluation techniques were used in the studies?
- **RQ8**: What peculiarities were diagnosed in legal texts?
- **RQ9**: What (syntactic/ semantic) anomalies were reported?
- **RQ10**: What standards were used for formalization?

By synthesizing the data from **RQ1** and **RQ2**, the maturity and trends of research types over the years can be traced. A conceptual framework (Casellas, 2011, p. 50) highlights the most common (overlapping) purposes of legal ontologies: ***Organization and structuring of information, Reasoning and problem solving, Semantic indexing and searching, Semantic integration and interoperation, and Understanding the domain***.

RQ3 looks at the underlying legal theories (and whether or not they were used). A legal theory (Casellas, 2011) needs to accurately describe a legal framework, seeking a faithful description for a cluster of legal phenomena arranged in a juridical system. Among many, the theories of Hart, Hohfeld, and Kelsen stand out.

Hans Kelsen (1881–1973) proposed a very broad (positivist) theory of law, where norms are basically rules, either observed, violated, or forcing people to perform desirable activities (Marmor, 2016). Herbert Hart (1907–1992) warned that the validity of the legal system falls under the social rule not the legal norm (Hart, Raz, Green, & Bulloch, 2012). Hart defined a distinction between two levels of norms: while those of the lower level regulate man's behavior in the social environment, second-level rules dictate the evolution of the legal system as a whole, defining how lower-level rules are created, revoked, violated, or enforced. Hohfeld's theory (1879–1918) defined the legal relations of opposites and correlatives (right, no-right, duty, no-duty or permission) (Hohfeld, 1913). Other contemporary theory focuses on normative positions, such as the type of rights to something (Alexy & Pulido, 2007).

Other minor legal theories are Intentional Legal Theory and Negotiation legal theory. Originalism or the Intention-oriented legal model (Brest, 1980) seeks to identify the intention of the legislator behind the law; that is, it transcends the literal interpretation of what is written. Negotiation theory, in turn, involves dealing with the vast body of existing negotiation law (consumer law and contract law, among others). The (positive) theory addresses different aspects of the law, be it the substance or the tactics/strategies of the negotiation (Korobkin, 2000). In addition, a classification scheme for the modeled legal sub-domains is presented in virtue of the research question **RQ4**.

With respect to the generalization level (**RQ5**) (that is, the level of nearness of the description to the world), Roussey, Pinet, Kang, and Corcho (2011) mention the following categories: Top (upper, foundational), General, Core, Domain, Task and Application ontology.

The other RQs are justified by the nature of the studies, such as the construction (**RQ6**) and assessment methodologies. In particular, concerning the ontology evaluation (**RQ7**), related literature (Brank, Grobelnik, & Mladenić, 2005) has proposed various approaches to assessment that cover the ontology as a whole or are addressed to specific levels (lexical, taxonomy, relations, context, syntactic, architectural) of the ontology. Brank et al. (2005) still list the techniques that can be performed: the **Gold Standard** evaluates ontologies based on one another or through checklists; **Case-Based** evaluation is an assessment based on a case or a specific application; **Data-Driven** is evaluated based on other existing domain data; and finally, **User-Based** takes into account the user experience.

Other issues related to the legal nature of ontologies, such as the nuances of legal corpus (**RQ8**), and the likely semantic inconsistencies of legal texts (**RQ9**) are also highlighted, ending with the formalization standards adopted for editing ontologies (**RQ10**).

2.2. Search strategies and search string

Regarding the search method, an automated search in the following digital libraries and indexers was chosen: ***ACM Digital Library, IEEE Xplorer, Springer Link, Scopus, Web of Science, Engineering Village and Science Direct***.

For the search string, terms related to the topic(s) of the search were identified and grouped through "AND" and "OR" logical operators. The first two groups list the synonyms for "ontology" and "legal". However, it is common to use other non-related terms (norms, legal knowledge, legal concepts, "AI & Law") such as "Ontologies for the Legal Domain" or "Ontologies of legal concepts". A third group was therefore created:

- **Group 01**: *Ontology, Ontologies, Ontological*;
- **Group 02**: *Law, Legal, Juridical*;
- **Group 03**: *Domain, Concept, Norm, Code, Knowledge, Information, Document, Text, Reasoning, AI & Law*;

During this phase, we decided to use a combination of these terms to cover as much as possible the topic. We additionally used a test set of pre-defined articles, that should be returned in the search (Breuker, Elhag, Petkov, & Winkels, 2002; Breuker & Hoekstra, 2004a; Ceci & Gangemi, 2016; Cornoiu & Valean, 2015; Freitas, Candeias, & Stuckenschmidt, 2011; Gangemi, Sagri, & Tiscornia, 2003; Hoekstra, Breuker, Di Bello, & Boer, 2009; Rodrigues, Azevedo, Freitas, da Silva, & da Silva Barros, 2015; Valente, Breuker, & Brouwer, 1999; van de Ven, Hoekstra, Breuker, Wortel, & Ali, 2008).

The databases have certain limitations and different ways of working that prevent a more efficient automated search. The search string, therefore, must be flexible to adapt and ameliorate these problems. Some databases do not allow a search on parts of the text, such as ***Springer***, adding considerable effort to the early stages of selection. Search strings are detailed in Table 1.

2.3. Inclusion/Exclusion criteria

In order to reduce biased sources, considering the proposal made by Petersen et al. (2015), two reviewers were needed. Two forms were also used: one to extract the data from the selected primary studies, and another for the excluded studies, indicating the reason for exclusion. Studies were selected that propose or apply a legal ontology for the field of law. The study must have been published in a journal, conference, or peer-reviewed workshop, must be available in English and electronically accessible. The following exclusion criteria (EC) were adopted:

- **EC01**: The study focuses only on a philosophical view, or the ontology is not presented in fact, or it is not a legal ontology;
- **EC02**: The study presents a superficial ontology to exemplify a new methodology or technique;
- **EC03**: The study presents comparisons/overviews of ontologies of other primary studies;
- **EC04**: The study has no abstract;
- **EC05**: The study is an unpublished text, available only as a summary, tutorial, presentation, talk, poster, technical report, thesis, or dissertation;
- **EC06**: The study is not in English;
- **EC07**: The study is not available electronically;
- **EC08**: The study is a duplicate of another study already included.

The selection of the publications was performed in three well-defined steps: (i) application of the search expression on the digital libraries, focusing on the title, abstract, and keywords, resulting in a first set of studies; (ii) application of inclusion/exclusion filters over the Title-Abstract-Keyword triad in the findings, resulting in a more-refined set of studies; and finally (iii) full-text screening, only for the studies approved in the previous step, removing any which met any of the exclusion criteria. The final output became the sample of papers used for the SMS. Doubts that arose about the importance of some manuscripts, made it important to follow the process until the end for complete reading.

3. Carrying out the SMS

This section has been outlined in three parts. First, the studies were identified. Then, data was extracted, mapping the evidence found, whenever necessary. Therefore, it was possible to answer the research questions raised. Following this, the results found were analyzed.

Table 1
String used per database.

Database	Query
ACM	acmdlTitle:((“legal ontology” OR “legal ontologies” OR “law ontology” OR “law ontologies” OR “juridical ontology” OR “juridical ontologies” OR ((“legal domain” OR “legal concept” OR “legal norm” OR “legal code” OR “legal knowledge” OR “legal information” OR “legal document” OR “legal text” OR “legal reasoning” OR (“AI” AND “law”)) AND (“ontology” OR “ontologies” OR “ontological”)))) OR recordAbstract:((“legal ontology” OR “legal ontologies” OR “law ontology” OR “law ontologies” OR “juridical ontology” OR “juridical ontologies” OR ((“legal domain” OR “legal concept” OR “legal norm” OR “legal code” OR “legal knowledge” OR “legal information” OR “legal document” OR “legal text” OR “legal reasoning” OR,(“AI” AND “law”)) AND (“ontology” OR “ontologies” OR “ontological”)))) OR keywords.author.keyword:((“legal ontology” OR “legal ontologies” OR “law ontology” OR “law ontologies” OR “juridical ontology” OR “juridical ontologies” OR ((“legal domain” OR “legal concept” OR “legal norm” OR “legal code” OR “legal knowledge” OR “legal information”,OR “legal document” OR “legal text” OR “legal reasoning” OR (“AI” AND “law”)) AND (“ontology” OR “ontologies” OR “ontological”)))
IEEE	**Substring01**: (“Document Title”:“legal ontology” OR “Document Title”:“legal ontologies” OR “Document Title”:“law ontology” OR “Document Title”:“law ontologies” OR “Document Title”:“juridical ontology” OR “Document Title”:“juridical ontologies” OR “Abstract”:“legal ontology” OR “Abstract”:“legal ontologies” OR “Abstract”:“law ontology” OR “Abstract”:“law ontologies” OR “Abstract”:“juridical ontology” OR “Abstract”:“juridical ontologies” OR”Author Keywords”:“legal ontology” OR “Author Keywords”:“legal ontologies” OR “Author Keywords”:“law ontology” OR “Author Keywords”:“law ontologies” OR “Author Keywords”:“juridical ontology” OR “Author Keywords”:“juridical ontologies”) **Substring02**: ((“Document Title”:“legal domain” OR “Document Title”:“legal concept” OR “Document Title”:“legal norm” OR “Document Title”:“legal code” OR “Document Title”:“legal knowledge” OR “Document Title”:“legal information” OR “Document Title”:“legal document” OR “Document Title”:“legal text” OR “Document Title”:“legal reasoning” OR (“Document Title”:“AI” AND “Document Title”:“law”)) AND (“Document Title”:“ontology” OR “Document Title”:“ontologies” OR “Document Title”:“ontological”)) OR ((“Abstract”:“legal domain” OR “Abstract”:“legal concept” OR “Abstract”:“legal norm” OR “Abstract”:“legal code” OR “Abstract”:“legal knowledge” OR “Abstract”:“legal information” OR “Abstract”:“legal document” OR “Abstract”:“legal text” OR “Abstract”:“legal reasoning” OR (“Abstract”:“AI” AND “Abstract”:“law”)) AND (“Abstract”:“ontology” OR “Abstract”:“ontologies” OR “Abstract”:“ontological”)) OR ((“Author Keywords”:“legal domain” OR “Author Keywords”:“legal concept” OR “Author Keywords”:“legal norm” OR “Author Keywords”:“legal code” OR “Author Keywords”:“legal knowledge” OR “Author Keywords”:“legal information” OR “Author Keywords”:“legal document” OR “Author Keywords”:“legal text” OR “Author Keywords”:“legal reasoning” OR (“Author Keywords”:“AI” AND “Author Keywords”:“law”)) AND (“Author Keywords”:“ontology” OR “Author Keywords”:“ontologies” OR “Author Keywords”:“ontological”))
SPRINGER	(“legal ontology” OR “legal ontologies” OR “law ontology” OR “law ontologies” OR “juridical ontology” OR “juridical ontologies” OR ((“legal domain” OR “legal concept” OR “legal norm” OR “legal code” OR “legal knowledge” OR “legal information” OR “legal document” OR “legal text” OR “legal reasoning” OR (“AI” AND “law”)) AND (“ontology” OR “ontologies” OR “ontological”)))
SCOPUS	**Substring01**: TITLE-ABS-KEY (“legal ontology” OR “legal ontologies” OR “law ontology” OR “law ontologies” OR “juridical ontology” OR “juridical ontologies”) **Substring02**: TITLE-ABS-KEY (((“legal domain” OR “legal concept” OR “legal norm” OR “legal code” OR “legal knowledge” OR “legal information” OR “legal document” OR “legal text” OR “legal reasoning” OR (“AI” AND “law”)) AND (“ontology” OR “ontologies” OR “ontological”)))
Web of Science	TS = (“legal ontology” OR “legal ontologies” OR “law ontology” OR “law ontologies” OR “juridical ontology” OR “juridical ontologies” OR ((“legal domain” OR “legal concept” OR “legal norm” OR “legal code” OR “legal knowledge” OR “legal information” OR “legal document” OR “legal text” OR “legal reasoning” OR (“AI” AND “law”)) AND (“ontology” OR “ontologies” OR “ontological”)))
Engineering Village	for 1969-2018 (((“legal ontology” OR “legal ontologies” OR “law ontology” OR “law ontologies” OR “juridical ontology” OR “juridical ontologies” OR ((“legal domain” OR “legal concept” OR “legal norm” OR “legal code” OR “legal knowledge” OR “legal information” OR “legal document” OR “legal text” OR “legal reasoning” OR (“AI” AND “law”)) AND (“ontology” OR “ontologies” OR “ontological”)))) WN KY)
Science Direct	TITLE-ABSTR-KEY(“legal ontology” or “legal ontologies” or “law ontology” or “law ontologies” or “juridical ontology” or “juridical ontologies”) or TITLE-ABSTR-KEY(((“legal domain” or “legal concept” or “legal norm” or “legal code” or “legal knowledge” or “legal information” or “legal document” or “legal text” or “legal reasoning” or (“AI” and “law”)) AND (“ontology” or “ontologies” or “ontological”)))

3.1. Identifying the primary studies

The SMS was executed following the planing activities, based on the searches performed on the indexers and databases mentioned. It is worth mentioning that important journals in the area are indexed by the search engines mentioned above, therefore, a manual search was not mandatory.

Based on the search string, 38 studies were returned from ACM, 32 from IEEE, 3,167 from Springer, 584 from Scopus, 313 from Compendex, 16 from Science Direct, and 165 from Web of Science, a total of 4315 studies. The large number of manuscripts returned by Springer occurred because of the lack of a base to filter the search for the title, abstract, and keywords. The findings in this first phase (P1) were sent to the second phase (P2), where specific sections were read and an evaluation w.r.t. the exclusion criteria were performed. As a result, 193 studies were selected, corresponding to 4.47% of the initial amount. Table 2 shows the results.

Finally, the complete reading of the studies was performed (third phase, P3), resulting in 78 included primary studies (P.S.). Among the excluded studies, the main causes of exclusion were: the text did not present an ontology or presented a very superficial one, the text was not available in the English language, or it was an older (or a superficial overview) version of a study already included. Table 2 presents these data, labeled with S. (superficial), N. (not in English), or R. (repeated). The final percentage distribution per database is illustrated in Fig. 2.

The Compendex indexer did not contribute any studies. This is partly due to the repetition of studies returned by the indexer in comparison to the results returned by the digital publisher libraries (IEEE, ACM and Springer). Among the indexers, Scopus stood out.

3.2. Answering the research questions

The purpose of **RQ1** is to investigate when the studies were published and the publication vehicles. Fig. 3 shows the evolution of publications over the years.

During the planning of the SMS, the mapping was not restricted to a specific time interval. Although some classic works addressing AI & Law date back to the 1970s (McCarty, 1977) and 1980s (McCarty, 1989; Rissland, 1988), it was really in the 1990s that legal ontologies became an active research field. Studies in this area increased significantly in recent years, persisting into the current decade. This follows the emergence and adoption of Semantic Web technologies, with direct impact in the area of AI & Law, during the first half of the last decade. The topic remains relevant and is the target of numerous studies. Approximately 50% of the studies found were published in the current decade.

Table 2
Result of systematic mapping.

Sources	*P1*	*P2*	*P3*				*Selected Studies*
			Excluded			*P.S.*	
			S.			*N.*	*R.*
ACM	38	18	07	0	01	**10**	Abrahams et al. (2011), Baumann and Loës (2010), Barabucci et al. (2013), Casellas et al. (2007), Freitas et al. (2011), Hoekstra et al. (2009), Mommers (2003), Nadah et al. (2007), Rodrigues et al. (2015), Winkels et al. (2010)
IEEE	32	25	13	01	02	**09**	Breaux and Powers (2009), Brighi (2004), Cornoiu and Valean (2015), Lee et al. (2011), Lovrencic and Tomac (2006), Mittal et al. (2016), Rodrigues et al. (2016), Sagri and Tiscornia (2003), Tiscomia (2001)
SPRINGER	3,167	46	17	01	04	**24**	Adams (2008), Agnoloni and Tiscornia (2010), Bagby and Mullen (2007), Barabucci et al. (2010), Bartolini et al. (2017), Boella et al. (2004), Bui et al. (2014), Cevenini et al. (2008), Corcho et al. (2005), Costilla et al. (2005), Drumond and Girardi (2008), Gómez-Pérez et al. (2006), Hu et al. (2011), Jarrar et al. (2003), Kurematsu and Yamaguchi (1997), Lehmann et al. (2004), Lu et al. (2012), Mitre et al. (2006), Panagiotopoulos et al. (2011), Saravanan et al. (2009), Stolarski and Tomaszewski (2008), Tantisripreecha and Soonthornphisaj (2011), Wyner and Hoekstra (2012), Zarri (2007)
SCOPUS	584	82	40	03	11	**28**	Ajani et al. (2016), Antunes et al. (2014), Boonchom and Soonthornphisaj (2012), Breuker et al. (2002), Breuker and Hoekstra (2004a), Buey et al. (2016), Cappelli et al. (2007), Casellas et al. (2010), Ceci and Gangemi (2016), Cernian et al. (2013), Delgado et al. (2003), Distinto et al. (2016), Gangemi et al. (2003), Gostojic et al. (2013), Griffo et al. (2016), Jinhyung et al. (2012), Lu and Ikeda (2008), Machado and Oliveira (2014), McClure (2007), Mimouni (2013), Rodríguez-Doncel et al. (2014), Rubino et al. (2006), Salam (2007), Shaheed et al. (2005), Shankhdhar and Darbari (2015), Tiscornia (2006), van de Ven et al. (2008), Zhang et al. (2015)
COMPENDEX	313	02	02	0	0	**0**	
SCIENCE DIRECT	16	07	0	02	0	**05**	de Gracia Carrión Delgado (2015), Ghosh et al. (2017), Hage and Verheij (1999), Valente et al. (1999), van Kralingen et al. (1999)
WEB OF SCIENCE	165	13	10	0	01	**02**	Bruckschen et al. (2010), van Laarschot et al. (2005)
Total	**4,315**	**193**	**89**	**07**	**19**	**78**	

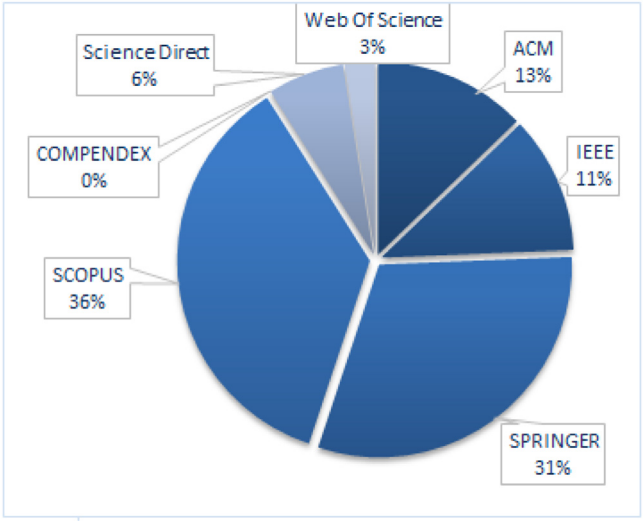

Fig. 2. Distribution per database.

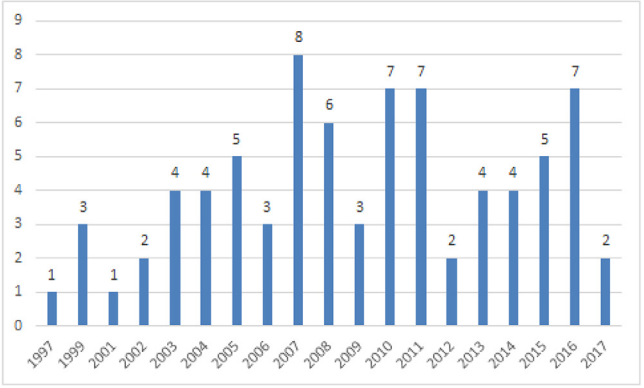

Fig. 3. Primary studies by year.

From another perspective, **RQ1** investigated the publication vehicles in order to ascertain the maturity of the area, and to list its principal venues. The distribution identified was as follows: 25 articles from journals, 36 from conferences, 13 from workshops, and 4 from book chapters. Although originally not in the scope of the mapping, both reviewers decided to include the mentioned chapters because they are actually collections of research papers reporting primary studies. It is also worth noting the small number of papers published at workshops, which reveals the quality of the research carried out under the umbrella of AI & Law. For purposes of analysis and clarification, the entire classification scheme can be found in Appendix A

3.2.1. Legal theories by purpose of ontology

Continuing with the classification scheme, the results of questions **RQ2, RQ3**, and **RQ5** are presented through two bubble charts. Each one represents a Cartesian plane, where the perpendicular axis contain the possible responses to the questions. The bubble occupies the intersection between these lines, representing the quantity of studies for each category pair.

Fig. 4 displays two categories: that of the underlying legal theories on the Y axis, and that of the purpose of the ontology on the X axis. Although legal sciences must fit into some legal theory to orient them, it was common to identify studies that did not bother to align their models in solid theories of law justification. Therefore, the “undefined” type was added to group these studies. Another observation is that, for both categories, the classifications are not disjoint; on the contrary, several works covering different theories have been identified, serving different purposes.

Undoubtedly, as a reflection of the maturity of positive theories, the Kelsen-Hart-Hohfeld triad represents the vast majority

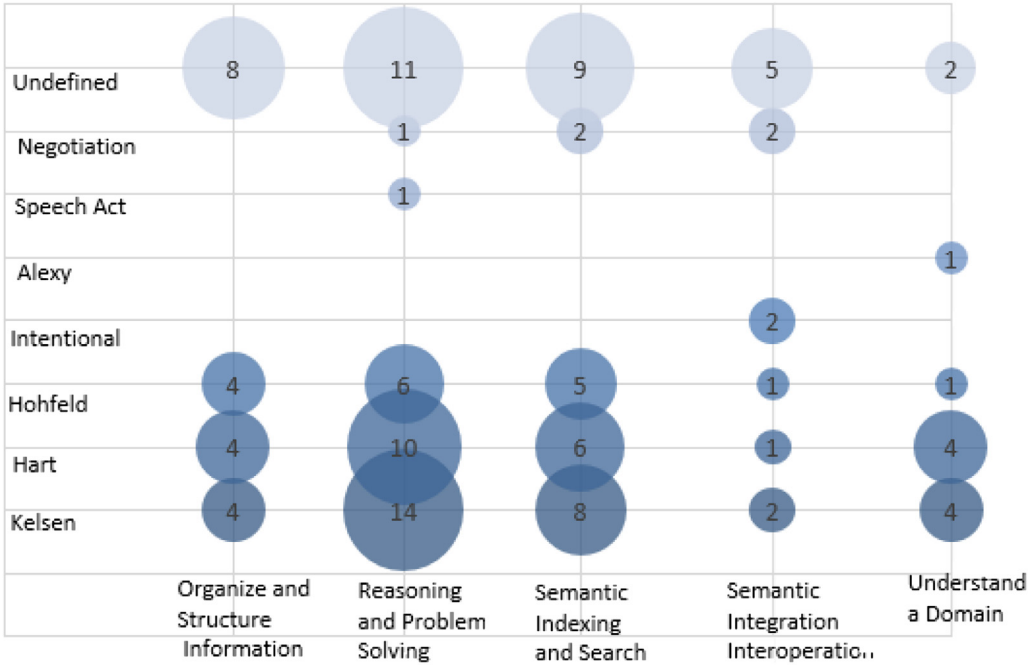

Fig. 4. Legal theories by purpose of ontology.

of legal foundations. In fact, these theories run through the legal systems of countless countries, creating a kind of "quasi-standard" (Breuker & Hoekstra, 2004b). In an orthogonal view, these theories are almost wholly linked to three main functions for ontologies: describing things / domains / phenomena (through lightweight ontologies), axiomatizing domains to substantiate and solve problems (through heavyweight ontologies), and indexing legal content to promote semantic-based searches.

In particular, considering ontologies built to solve problems, some studies have proposed expert systems for a number of applications. We have identified ontology-based prototypes/tools for simulation of legal acts in the criminal sphere (such as LEGIS Freitas et al., 2011; Rodrigues et al., 2015; Rodrigues, Freitas, & Azevedo, 2016, and CORBS Ghosh, Naja, Abdulrab, & Khalil, 2017) as well as related to benefits act for the Dutch Unemployment Law (FRAMER van Kralingen, Visser, Bench-Capon, & van den Herik, 1999). An intelligent system to automatically determine the potential liability of actors was implemented in van Laarschot, Steenbergen, Stuckenschmidt, Lodder, and van Harmelen (2005) (the Best System). Other intelligent applications address queries about possible conflicts (Legal Atlas Winkels, Hoekstra, & Hupkes, 2010), especially when norms govern the same situation but with different deontic notions (permitting and prohibiting a situation, for example), such as the Judging Amy system (van de Ven et al., 2008). Likewise, ontology-based applications based on legal knowledge to solve potential legal disputes between corporations are described in Abrahams, Condliffe, and Zeleznikow (2011). Expert systems playing the role of recommender applications were identified in Drumond and Girardi (2008) (the Infonorma multi-agent system) and in Jinhyung, Hwang, Jung, and Sung (2012) (iLaw). The primary purpose of these systems is to recommend legal artifacts/instruments related to a specific case-based entry. Finally, a decision support system capable of reasoning about the most appropriate license for a digital content was proposed and developed by Nadah, de Rosnay, and Bachimont (2007), known as Medialex.

In a smaller number, the roles of semantic integration, and ontologies as explanatory descriptions of the nature of the domain appear in the rightmost part of Fig. 4. With respect to semantic interoperability, some categories could be highlighted, such as: **integration of laws from multiple jurisdictions** (Distinto, d'Aquin, & Motta, 2016; Hu, Wu, & Yang, 2011; Jarrar, Verlinden, & Meersman, 2003; Panagiotopoulos, Gionis, Psarras, & Askounis, 2011), **legal harmonization of selected corpus/data sets of documents** (such as regulations, directives, and case law as described in Agnoloni & Tiscornia, 2010 and Barabucci, Di Iorio, Poggi, & Vitali, 2013), **legal harmonization between languages standards addressing specific domains** (such as digital rights licenses as highlighted in Nadah et al., 2007), or **harmonization between technical and legal perspectives** (Cevenini, Contissa, Laukyte, Riveret, & Rubino, 2008). In essence, harmonization seeks to capture common knowledge elements, bypassing the barriers of semantic heterogeneity and dispersion of data. A new category of harmonization for cross-border platforms was also highlighted, with a special focus on the intention behind the law (Brest, 1980). Not surprisingly, all articles framed by the legal theory of intention (Lu, Xiong, & Park, 2012), Lu and Ikeda (2008) also fit into the category of semantic integration.

Considering that the ultimate purpose of law ontologies is to understand the domain, there are very few studies that do not properly follow a legal theory. As knowledge about the domain is detached from the domain itself, philosophical theories are sought that can explain the nature of the different types of knowledge identified. In other words, to explain any conceptual flawless domain, it is necessary to strengthen the links with the underlying theories. Even taking into account the two studies classified as "undefined", in Mommers (2003) there is a reference to the dual "ontology v. epistemology" relationship, in which the epistemological discipline scrutinizes the acquisition, object, and justification of knowledge. In Adams (2008), a (shallow) reference to an "utilitarian rationale of intellectual property" as a theory of justification can be found.

3.2.2. Legal theories by ontology generalization level

The relationship between legal theories and the generalization level is analyzed through a similar bubble chart (Fig. 5). At first glance, it is clear that the studies focused primarily on 3 levels of granularity: upper, core and domain. As the SMS has evolved

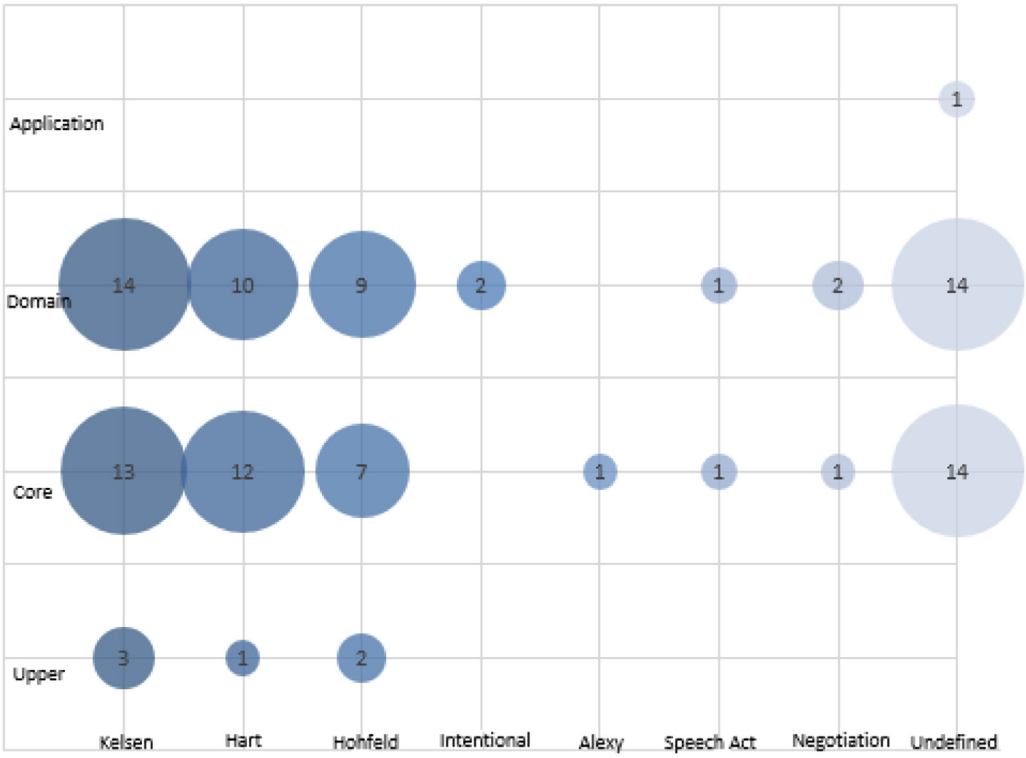

Fig. 5. Legal theories by ontology generalization level.

specifically around the legal realm, it should not be expected to find general or task ontologies, whose definitions imply cross-domain notions.

Again, positive theories were the principal choices, opening other likely paths of research with more contemporary theories, such as those involving the ruling principles of the Constitutional State of Law (Alexy's theory Alexy & Pulido, 2007).

Five studies depicting top ontologies were identified in the mapping. The **Legal Requirements Upper Ontology** (Breaux & Powers, 2009) defines "legal concepts used to specify legal requirements for organization compliance requirements". The **Top Ontology of the Law** (Hage & Verheij, 1999) configures a particular "view of the law as a dynamic system of states of affairs, which are connected by events and rules". **CausatiOnt** (Lehmann, Breuker, & Brouwer, 2004) is an upper ontology developed as a basis for modeling physical and agent causation fostered as a framework heavily embedded in Hart's legal theory to conceptualize and to address issues regarding legal responsibility. An upper level Ontology was also the main concern of Zarri (2007) – known as **HClass** – to represent narratives as an ontology of events. Finally, **NM-L** (Shaheed, Yip, & Cunningham, 2005) is a top-level extension w.r.t. the legal domain "seeking to found the thematic analysis of natural language in a commonsense view of reality". In fact, NM-L is appropriately an intermediate view between the top and the core level. At the other end, only one application ontology was found: an OWL ontology for the legal cases of Popov v. Hayashi (Wyner & Hoekstra, 2012).

Before categorizing the core ontologies identified, the distinction proposed by Agnoloni and Francesconi (2011) highlighting the different profiles that exist in legislative documents was used, with the structural (or formal) representing the traditional division of the law into norms, articles, paragraphs, and sections, and the semantic profile, which considers the substantial interpretation of the text, generally expressed by normative provisions. According to the first classification, studies were identified to link between the norms by creating a navigable network (and thus facilitating procedures such as evolution, creation, and derogation) (Brighi, 2004; Lee et al., 2011; Machado & Oliveira, 2014; McClure, 2007; Mimouni, 2013), or to further decompose the normative instruments into their constituent elements (**Lex-is** (Cornoiu & Valean, 2015), **OntoJuris** (Barabucci, Cervone, Palmirani, Peroni, & Vitali, 2010; Drumond & Girardi, 2008; Shankhdhar & Darbari, 2015)), or both, such as the **Legislative Ontology** (Costilla, Palacios, Cremades, & Vila, 2005).

Regarding the semantic profile, other inner categories were further identified. Some studies were carried out in order to clarify the different types of knowledge involved in the domain (like the well-known **FOLAW** (Valente et al., 1999)) or how it relates specifically to the domain itself (Mommers, 2003). There are also studies that revolve around knowledge outside the written perspective (in Casellas et al. (2007) there is a professional juridical ontology, **OPJK**). A second group lists the studies considered more traditional in the sense of conceptualizing generic entities present in juridical texts, such as agents, events, and roles (such as **LKIF** (Hoekstra et al., 2009), **LRI-Core** (Breuker & Hoekstra, 2004a), **FunGramKB** (de Gracia Carrión Delgado, 2015), **iLaw** (Jinhyung et al., 2012), **LOTED2** (Distinto et al., 2016), as well as Cernian, Carstoiu, Vasilescu, and Olteanu (2013), Corcho, Fernández-López, Gómez-Pérez, and López-Cima (2005), Kurematsu and Yamaguchi (1997), Tiscomia (2001), van Kralingen et al. (1999)). From this same perspective, other studies focused on modeling entities of other legal matters, such as judicial acts (the **Core Legal Ontology (CLO)** of Gangemi et al. (2003)), legal relations (**UFO-L** of Griffo, Almeida, & Guizzardi (2016)), agent behavior in Boella, Lesmo, and Damiano (2004), and deontic modalities in Gostojic, Milosavljevic, and Konjovic (2013) and Rubino, Rotolo, and Sartor (2006).

Some ontologies have been also built for very specific purposes, with a likely negative effect of undermining their reusability in other contexts. This is the case with shallow ontologies used as wordnet vocabulary such as **JurWordnet** (Sagri & Tiscornia, 2003)

and the taxonomy syllabus proposed by Ajani et al. (2016). Semantic Integration (McClure, 2007) and semantic retrieval of legal documents (Buey, Garrido, Bobed, & Ilarri, 2016; Bui, Nguyen, & Ho, 2014; Tantisripreecha & Soonthornphisaj, 2011) round out the defined-purpose core ontologies.

3.2.3. Mapped legal sub-domains

The final observation, still regarding generalization level, was to identify those ontologies classified as belonging to the domain level that are specifically the sub-domains from the juridical universe under analysis (research question **RQ4**). This concern comes from a single line of reasoning: when creating a criminal ontology, for example, the engineer should know what has been produced beforehand, and analyze the assumptions, criteria, choices, and theories already achieved in practice. This can elevate ontological engineering to a plateau where reusability ceases to be a distant and inaccessible target.

Twelve legal sub-domains were identified: Traffic Law, Tax Law, Civil Law, Local Government Law, Labor Law, Succession Law, Commercial Law, Contractual Law, Consumer Law, Criminal Law, Privacy Law, and License Law.

An information-sharing-centered world is sometimes at cross-purposes with data security. Therefore, ontologies for legal policy enforcement, such as information sharing and data protection in the cloud, are concerns of recurrent research such as Hu et al. (2011), as well as **OntoPrivacy** (Cappelli, Bartalesi, Sprugnoli, & Biagioli, 2007), the **Neurona Project** (Casellas et al., 2010), and the **LegLOPD** (Mitre, González-Tablas, Ramos, & Ribagorda, 2006).

Similar concerns exist for intellectual property rights law and licensing of digital content. Some of these studies are: the **Law Article Ontology** (Lu et al., 2012), the **ALIS IP** (Cevenini et al., 2008), the **International Copyright Law Ontology, ICLOnto** (Lu & Ikeda, 2008), and the **Ontology for Digital Rights Management, IPROnto** (Delgado, Gallego, Llorente, & García, 2003). Trade issues also provide a perspective where harmonization of multiple jurisdictions occurs, in light of the growth of electronic commerce (Bagby & Mullen, 2007; Stolarski & Tomaszewski, 2008).

Contractual laws stand out in this legal landscape. This is how ontologies in Gómez-Pérez, Ortiz-Rodríguez, and Villazón-Terrazas (2006) and Mittal, Joshi, Pearce, and Joshi (2016) are presented, that is, capable of representing real-estate transactions when delivering cloud services to the citizen. Contracts may enter into agreements that cross geographical barriers (such as the **Ontology of Contracts for the International Sale of Goods** (Kurematsu & Yamaguchi, 1997)) or operate only in local context-like situations, such as loan agreements (van de Ven et al., 2008). Consumer law is not left behind, having five representative studies. A customer complaint ontology (**CContology**) is the object of study in Jarrar et al. (2003). Rodríguez-Doncel, Santos, and Casanovas (2014) consider consumer complaints in the European Union through a semantic model that represents incidents related to air travel. The SMS has further identified an ontology for the consumer code **JudO Core ontology**: a judicial model attempting to represent judicial interpretations throughout hearings based on the analysis of other relative precedent cases (Ceci & Gangemi, 2016). Last but not least, economic and legal interests were mapped into a consumer protection ontology: the **DALOS ontology** (Agnoloni & Tiscornia, 2010), and a multilingual semantic lexicon to be used as semantic metadata within the consumer code domain was presented in Tiscornia (2006), the **LOIS Wordnet**.

The Criminal domain covers a set of entities, roles, and actions, which has attracted a great deal of attention from engineers and experts in the field. In this context, the studies produced by Breuker et al. (2002) (the **Dutch Criminal Law, OCL.NL**), Shankhdhar and Darbari (2015) (the **Indian Criminal law**), Rodrigues et al. (2015) (the **Brazilian Criminal Law, OntoCrime**) and Ghosh et al. (2017) (the **Lebanese Criminal Law**) are highlighted. What is curious is that the criminal field opens up a range of smaller domains, appealing to the types of knowledge involved and the new possibilities of reasoning that they raise. Rodrigues et al. (2015) tackle the inherent ambiguities and conflicts of the legal process and principles of conciliation, demonstrated through an ontology that models the norms of crimes related to the drinking-and-driving law. In another paper, Rodrigues et al. (2016) address what would be an ontology of crimes against property, noting some conceptual disparities between what is written in legal documents and what is used in the courts.

Among the less often mentioned sub-domains, Winkels et al. (2010) propose to merge purely textual information with geospatial data in order to map specific regions and infer, for example, possible activities in certain locations (local government law). It therefore establishes a new hybrid model in which the ontologies use images and legal texts together. van Kralingen et al. (1999) present a conceptual frame-based ontology to represent norms, acts and legal concepts for the **Dutch unemployment benefits act**. The civil code was also included because of the norms concerning legal relationships (Abrahams et al., 2011) and to conceptualize how inheritance is passed on to legitimate heirs (specifically treated as the law of Probate and Succession (Boonchom & Soonthornphisaj, 2012; Lovrencic & Tomac, 2006)). The last sub realms, Tax Law and Traffic Law, were dealt respectively in Saravanan, Ravindran, and Raman (2009) and Freitas et al. (2011). Saravanan et al. (2009) propose the **IR-oriented legal ontology**, an ontology for India Law on rent control, income tax, and sales tax related to civil court judgment. Freitas et al. (2011) have conceptualized a vehicular ontology, which may be reused in other contexts beyond the traffic code, such as with crimes related to the drinking-and-drive law.

3.2.4. Reused ontologies from literature

Lastly, the uppermost level ontologies/frameworks used as basis for the aforementioned core/domain ontologies were also recorded. The result found was: **DOLCE/DOLCE+** foundational ontology (used by Boella et al., 2004; Delgado et al., 2003; Gangemi et al., 2003; Gostojic et al., 2013; Sagri & Tiscornia, 2003; Tiscornia, 2006), **PROTON** (PROTo upper ontology used by Casellas et al., 2007), **CommonKADS** (modeling library and framework used by Valente et al., 1999; van Kralingen et al., 1999), **LKIF** (Legal Knowledge Interchange Format used by Bartolini, Muthuri, & Santos, 2017; Bui et al., 2014; Ceci & Gangemi, 2016; Cevenini et al., 2008; Distinto et al., 2016; Ghosh et al., 2017; Panagiotopoulos et al., 2011; Rodrigues et al., 2015; Rodríguez-Doncel et al., 2014; van de Ven et al., 2008), **LRI-Core** (used by Breuker et al., 2002; Delgado et al., 2003; Gostojic et al., 2013; Griffo et al., 2016; Mitre et al., 2006), **UFO** (Unified Foundational Ontology used by Ghosh et al., 2017; Griffo et al., 2016; Rodrigues et al., 2016), **Akoma Ntoso** (ontology of metadatas used by Barabucci et al., 2010; Barabucci et al., 2013), **CLO** (Core Legal Ontology used by Agnoloni & Tiscornia, 2010; Tiscornia, 2006), **SUMO** (the Suggested Upper Merged Ontology used by Delgado et al., 2003), **SKOS** (the Simple Knowledge Organization System Namespace used by Bartolini et al., 2017; Cornoiu & Valean, 2015), **PROV-O** (the Provenance Ontology used by Rodríguez-Doncel et al., 2014), and **FOLAW** (the functional ontology of law used by Adams, 2008; Lehmann et al., 2004). Fig. 6 displays this distribution.

A similar result was also achieved from the SMS proposed by Griffo, Almeida, and Guizzardi (2015), which focused exclusively on legal theories and core ontologies in order to reveal whether

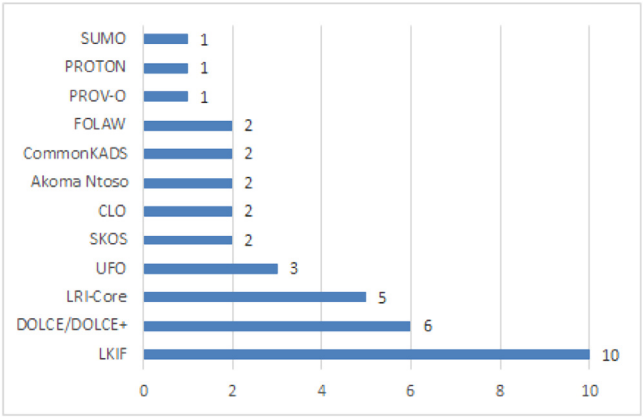

Fig. 6. Reused ontologies.

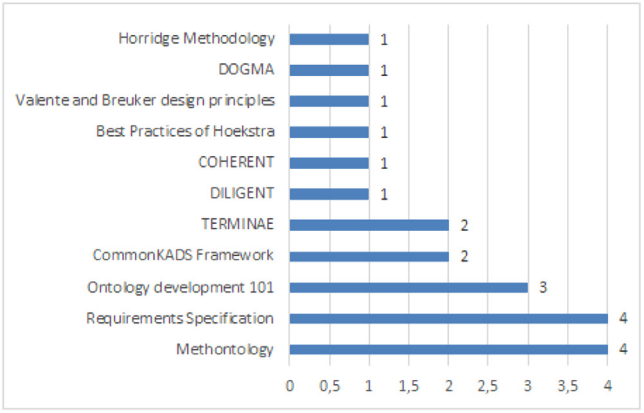

Fig. 7. Engineering methodologies and good practices.

the models produced are sufficiently extensible and philosophically well-rooted to address current societal challenges.

3.2.5. Ontological engineering approaches

This study seeks to categorize if and how the development of ontological models was guided by any well-defined construction approach (research question **RQ6**). Unfortunately, many studies have made it difficult to map because of the lack of information about the process of constructing the ontology, making it more difficult to understand whether the process was simply not mentioned or if it did not exist at all.

At first, this analysis identified whether the ontology was constructed manually or (semi) automatically. Of the 78 primary studies, only 05 fit this description, of which only Boonchom and Soonthornphisaj (2012) presented a fully automatic development. They have described the **Automatic Thai Legal Ontology Building (ATOB)**, an algorithm which, along with its automated construction process, is notable for improving the retrieval process of Thai legal sentences within the domain of succession law.

Partially automatic constructions were identified as well (Bruckschen et al., 2010; Ceci & Gangemi, 2016; Kurematsu & Yamaguchi, 1997; Lee et al., 2011). Lee et al. (2011) described how legal documents provided in markup languages are converted to standard Semantic Web format using two different ways methods: structure-based and semantics-based, according to specific "conversion rules". Thus, the semantics-based ontology is populated manually and enriched from available thesauruses. Other possibilities are to manually construct a "seed ontology", which can then be automatically enriched (Bruckschen et al., 2010; Kurematsu & Yamaguchi, 1997). Iterative tools can also contribute to ontological evolution (Tantisripreecha & Soonthornphisaj, 2011).

For the other 73 primary studies, idealization, conception, and implementation was carried out manually. For these cases, the analysis was based on three fundamental facets: (i) the methodological guide, (ii) the approach used, and (iii) the support tool. The studies could contain all three facets, or even none at all. Regarding the methodology, Fig. 7 illustrates the commonly employed life-cycle process, from least to most cited (from top to bottom of the chart, respectively).

Corcho et al. (2005) suggest that the success of **Methontology** (Corcho et al., 2005; Gómez-Pérez et al., 2006; Rodrigues et al., 2015; Stolarski & Tomaszewski, 2008) in the legal domain comes from its inherent ease-of-use (graphical and tabular intermediate representations), allowing legal experts without technical knowledge in ontological engineering to actively participate in its development. This observation also applies to the **Requirements Specification** methodology (Bartolini et al., 2017; Casellas et al., 2010; Panagiotopoulos et al., 2011; Rodríguez-Doncel et al., 2014), under the assumption that the presence of specialists strongly supports the validation of the ontology.

Ontology Development 101 (Cernian et al., 2013; Cevenini et al., 2008; Zarri, 2007) covers another concern: the need for an iterative, flexible process that can be used whenever a decision/assumption needs to be clarified better or refined, a situation that constantly occurs in the legal realm. This methodology also considers, in its initial phases, the reuse of existing ontologies. The **CommonKADS** method (Valente et al., 1999; van Kralingen et al., 1999) works on two perspectives: domain and control. The control perspective describes how the system should perform a given task or inference. Thus, CommonKADS is also a task library from which reasoning models can be extracted for specific legal-knowledge-based application development.

The **TERMINAE** method was used exclusively for the construction of domain legal ontologies (Mitre et al., 2006; Saravanan et al., 2009). Although in a smaller number (only one study of each was identified), other methodologies recognized in the literature were also present, as **DILIGENT** (Casellas et al., 2007), **COHERENT** (de Gracia Carrión Delgado, 2015) and **DOGMA** (Jarrar et al., 2003). It is also worth mentioning the principles and good practices conceived, adopted, and shared by specialists in the area of ontology development, such as the **best practices from Hoekstra** (Wyner & Hoekstra, 2012), **Valente and Breuker design principles** (Adams, 2008), and **Horridge guidelines** (Antunes, Caetano, & Borbinha, 2014).

Along another axis of analysis, the approaches considered here were taken from Uschold and Gruninger (1996), which emphasizes three strategies: **bottom-up** (domain-specific models are engineered mostly from text sources), **top-down** (models built from generic abstract concepts, refined through a specialization process), and **middle-out** (seeks to define intermediate categories of the fundamental elements in the domain). A **hybrid style**, which combines the first two, can also be used, balancing the trade-off between reusability and stability. In this mapping, fourteen primary studies followed the bottom-up strategy, another twelve were guided by the top-down strategy and the hybrid and middle-out approaches were identified in nine and two studies, respectively. Appendix A contains the distribution. Another observation (Fig. 8) is that the top-down approach is more linked with top-level ontologies while bottom-up focuses predominantly on domain ontologies. One plausible explanation is that core-ontologies need to fit into abstract categories of concepts at first. On the contrary, domain ontologies need to map knowledge closer to reality. The hybrid approach, in turn, does not present any major engagement level.

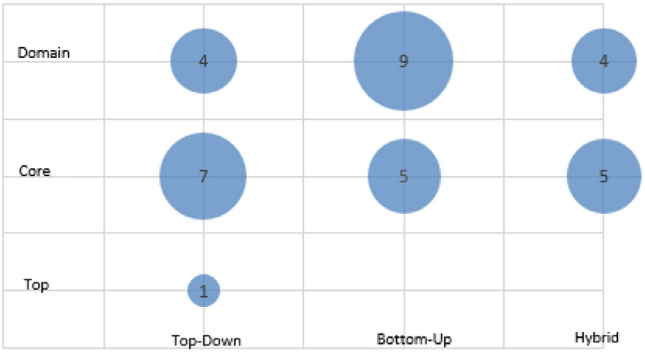

Fig. 8. Generalization level by engineering approaches.

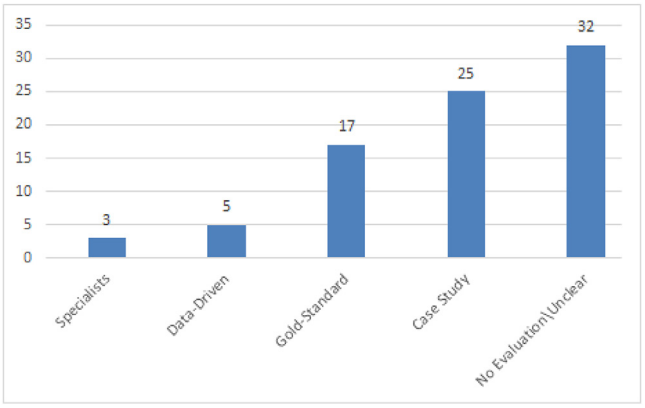

Fig. 9. Ontology evaluation approaches.

We further investigate the commonly used editing tools: **Protégé** (Abrahams et al., 2011; Bagby & Mullen, 2007; Bartolini et al., 2017; Breuker & Hoekstra, 2004a; Buey et al., 2016; Bui et al., 2014; Drumond & Girardi, 2008; Jinhyung et al., 2012; Lehmann et al., 2004; Lovrencic & Tomac, 2006; Panagiotopoulos et al., 2011; Rodrigues et al., 2015; Rubino et al., 2006; Salam, 2007; Saravanan et al., 2009; Shankhdhar & Darbari, 2015; van de Ven et al., 2008; Wyner & Hoekstra, 2012; Zarri, 2007), **OilEd Ontology editor** (van Laarschot et al., 2005), **HOZO** (Lu & Ikeda, 2008; Lu et al., 2012), **WebODE** (Corcho et al., 2005; Gómez-Pérez et al., 2006), **Dogma Modeler** (Jarrar et al., 2003) and **OntoUML** (Griffo et al., 2016; Machado & Oliveira, 2014).

3.2.6. Ontological evaluation approaches

The approaches used for legal ontology assessment based on the earlier-mentioned classification (Section 2.1) were investigated (**RQ7**), as well as whether or not the proposed ontologies had been evaluated in some manner. For the purposes of clarification, the **Gold Standard** category included those studies that either used methodologies for conceptual analysis, or those that relied on higher level ontologies which already employ modeling primitives that support the design of well-founded ontological models. Fig. 9 shows the distribution of the studies by the categories of assessment.

Although a reasonable number of studies were identified that did not bother to use the evaluation of the ontology produced (32 of the 78 primary studies selected, or 41%), it was possible to find relevant studies for all categories. As concrete legal cases and other examples of a more didactic nature are easily found on the web, this most likely influenced the choice of **Case Study** as the most adopted assessment approach. When speaking of core ontologies, these evaluations are conducted by instantiating their categories into more well-defined domains, such as described in Ajani et al. (2016), Gostojic et al. (2013), Rodrigues et al. (2015), Valente et al. (1999), van Kralingen et al. (1999) and Zarri (2007).

Instead of a standard model, in the **Gold Standard** category, studies are grouped according to a modeling profile "*proposed to evaluate and improve the conceptual quality of class hierarchies and concept taxonomies, and to solve some recurrent problems in the practice of conceptual modeling*" (Guizzardi, 2005). This is the case of the top-level DOLCE and UFO ontologies, which provide meta-properties (rigid, sortal) or stereotypical classes (kind, role, phase) and constraints motivated by semantic considerations, which together provide a framework of support for ontological well-founded design models (Bartolini et al., 2017; Boella et al., 2004; Gangemi et al., 2003; Ghosh et al., 2017; Hoekstra et al., 2009; Rodrigues et al., 2016). Also under this classification were grouped similar studies that explicitly used evaluation methodologies, such as the Ontoclean framework (Barabucci et al., 2013; Tiscomia, 2001; Wyner & Hoekstra, 2012), a domain-independent methodology relying on notions from philosophy to assess decisions about the ontological nature of the elements in subsumption relations, allowing the construction of untangled ontologies.

To a lesser extent, the **data-driven** or **expert-driven** test cases emerge. Data-driven test cases are, in general, studies supported by a database to classify entities referring to the legal domain, that is, they are used specifically for concept evaluation (Baumann & Loës, 2010; Bruckschen et al., 2010; Buey et al., 2016; Kurematsu & Yamaguchi, 1997; van Laarschot et al., 2005). What has been observed, however, is that the participation of legal experts during the process of construction of the ontologies is still in its incipient stages, especially in the evaluation phase. In this group, there is the **Ontology of Professional Judicial Knowledge** (Casellas et al., 2007), which has been evaluated and improved along with the magistrates of the Spanish judicial school, the **Ontology for India Tax Law** (Saravanan et al., 2009), verified by a human expert and legal judgments (court cases), and the **DALOS domain ontology** (Agnoloni & Tiscornia, 2010) evaluated by the Italian parliament.

3.2.7. Legal text problems

A diversity of particularities and nuances make the legal domain challenging in relation to other working domains, which must be duly addressed when producing systems for legal reasoning. It is possible to identify and categorize anomalies at the syntactic and semantic levels. In order to create a classification scheme, two steps were performed: first, the causes reported in the primary studies that are a recurrent source of anomalies in legal texts and reasoning were identified (**RQ8**); then the anomalies themselves were mapped (**RQ9**), at the levels mentioned.

Regarding the particularities of the domain of law in relation to the other commonly-adopted fields, five main factors were identified for the appearance of anomalies (Fig. 10): **writing style** (Ajani et al., 2016; Costilla et al., 2005; Mittal et al., 2016; Rodrigues et al., 2015; Saravanan et al., 2009), **heterogeneity of sources** (Adams, 2008; Barabucci et al., 2013; Buey et al., 2016; Costilla et al., 2005; Distinto et al., 2016; Jinhyung et al., 2012; Machado & Oliveira, 2014; Panagiotopoulos et al., 2011; Rodrigues et al., 2015; Rodrigues et al., 2016; Sagri & Tiscornia, 2003; Shankhdhar & Darbari, 2015; van Laarschot et al., 2005) **volume of information** (Bui et al., 2014; Casellas et al., 2010; Cernian et al., 2013; Cornoiu & Valean, 2015; Gómez-Pérez et al., 2006; Jinhyung et al., 2012; Lu & Ikeda, 2008; Mittal et al., 2016; Saravanan et al., 2009; Tantisripreecha & Soonthornphisaj, 2011; Tiscomia, 2001; van de Ven et al., 2008), **dynamicity of normative texts** (Ceci & Gangemi, 2016; Cernian et al., 2013; Cornoiu & Valean, 2015; Hage & Verheij, 1999), and **overlapping jurisdictions** (Agnoloni & Tiscornia, 2010; Ajani et al., 2016; Hu et al., 2011; Jarrar et al., 2003; Lu et al., 2012; Winkels et al., 2010).

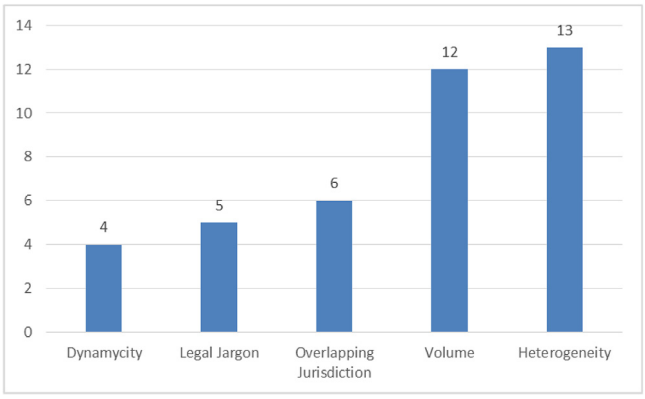

Fig. 10. Anomaly source.

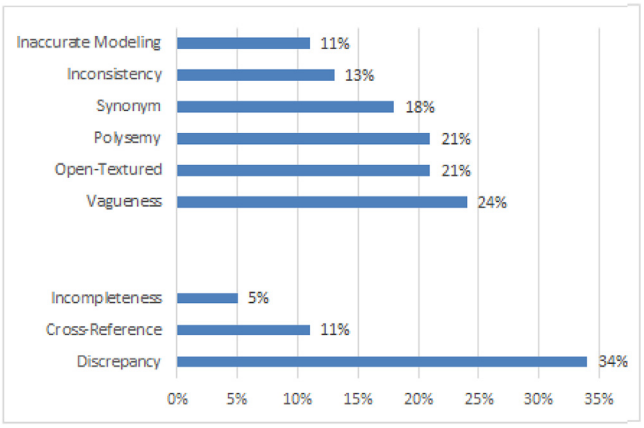

Fig. 11. Syntactic/Semantic anomalies.

The language used for drafting laws has always been recognized as obscure, with frequent use of archaism, erudition and other linguistic juggling (Costilla et al., 2005; Rodrigues et al., 2015), in addition to legal jargon (Mittal et al., 2016; Saravanan et al., 2009). Notably, the aspect that most stood out during this initial analysis of deficiencies was the heterogeneity of the sources of legal information. In a technical sense, it is called the source of law, as everything by which the Law (its rules) is given form. Depending on the type of legal system adopted, the sources may be: the law itself, jurisprudence (i.e. the global understanding of judges and lawyers on a particular subject), the traditional customs of a people or culture, or doctrines (i.e., general principles that underlie legal norms).

As well as being dispersed, the legal domain draws attention because of the volume of information it produces daily in legislative chambers, martial courts, courts of reconciliation, among others. Not to mention that from the point of view of jurisprudence, the past is regularly employed as a tool to enlighten the present. Accordingly, most of the studies that dealt with the volume of legal information have an ontological purpose to conceive of methods and tools for semantic indexing and search (Bui et al., 2014; Cernian et al., 2013; Cornoiu & Valean, 2015; Gómez-Pérez et al., 2006; Saravanan et al., 2009; Tantisripreecha & Soonthornphisaj, 2011; Tiscomia, 2001).

Additionally, the normative corpus is subject to modification, whether to adapt to the current context in which it is inserted or to correct eventual discrepancies that appear when observing the system as a whole. When changes are made without strict control, future modifications will be necessary, leading to a potential "snowball" effect. Finally, comparing and harmonizing different legislation is something that is continually studied, aided by the purpose of semantic integration described above. Unfortunately, the integration of cross-border norms from different cultures, languages, and social realities, tends to reveal distinct conceptualizations, gaps, and other ambiguities.

Apart from legal textual nuances, the second goal was to categorize syntactic and semantic anomalies (Freitas et al., 2011). Of the amount of studies selected, 38 highlighted syntactic and semantic anomalies. The upper part of Fig. 11 shows the semantic anomalies. Conversely, the syntactic anomalies are listed at the bottom.

Along the syntactic axis, three categories of anomalies were observed: incompleteness, discrepancy, and cross-referencing. Incompleteness consists of gaps in legislation, even though it is said that the legal system is holistically complete and uses other mechanisms (doctrines and principles) to resolve any incompleteness of the law itself (Ajani et al., 2016; Valente et al., 1999). Discrepancy refers to potential conflicts between norms, either of a merely apparent nature (Greco, 2017 states that when two or more norms may influence a fact, only one of those rules will apply in practice); or real, when the legal norms, within the same legal order, are incompatible. In general, courts use chronology, superiority, and time criteria to resolve these issues (Greco, 2017). Such conflicts were reported in Hu et al. (2011), Rodrigues et al. (2015), Rodrigues et al. (2016), van de Ven et al. (2008) and Winkels et al. (2010). Additionally, as a whole, legal systems present themselves as a collection of interconnected, interdependent documents with a vast amount of cross-references (Breaux & Powers, 2009; Lee et al., 2011; Mimouni, 2013; van de Ven et al., 2008).

Semantic anomalies revolve around ambiguities, whether related to grammar or conceptualization. Evidence for these deficiencies is reported by Ajani et al. (2016): "*[...] Ambiguity, terms of its own that are often obscure, subject to changes over time, contextually defined, ill-defined, subject to interpretation to deal with their vagueness, defined in incompatible ways in different legal sources, or difficult to translate into different languages*". Therefore, the following anomalies are reported: Polysemy, Synonym, Inconsistencies, Under-specification, Open-textured concepts, and Inaccurate Modelling.

Polysemy occurs when it is possible to assign more than one meaning to the same word. This is the case reported in Freitas et al. (2011) in relation to the Portuguese word "*Carroceria*", which has two meanings in the Brazilian traffic code: it refers to the structure on which the car is built (chassis), or to the back of certain types of vehicles usually used to transport things (truck bed). In addition to the aforementioned study, polysemy is pointed out as a semantic shortcoming in a reasonable amount of studies (Ajani et al., 2016; Gangemi et al., 2003; Griffo et al., 2016; Nadah et al., 2007; Sagri & Tiscornia, 2003; Saravanan et al., 2009; Tiscornia, 2006). Synonyms are presented as anomalies when they cause semantic redundancy (Breuker et al., 2002; Casellas et al., 2007; Cevenini et al., 2008; Nadah et al., 2007; Sagri & Tiscornia, 2003; Saravanan et al., 2009; Tiscornia, 2006). In Cevenini et al. (2008), synonyms are even singled out as a source of more frequent anomalies than polysemy. It is also important to emphasize the "near-synonym" (Tiscornia, 2006), that is, terms with similar meanings, even though not exactly the same.

With regard to conceptualization, the presence of semantic spaces or vague terms favors the appearance of under-specifications. This anomaly impairs the accuracy of the model in relation to reality (Ajani et al., 2016; Breuker et al., 2002; Cornoiu & Valean, 2015; Freitas et al., 2011; Ghosh et al., 2017; Lehmann et al., 2004; Lovrencic & Tomac, 2006; Rodrigues et al., 2016; Saravanan et al., 2009). A similar phenomenon inherent to the legal

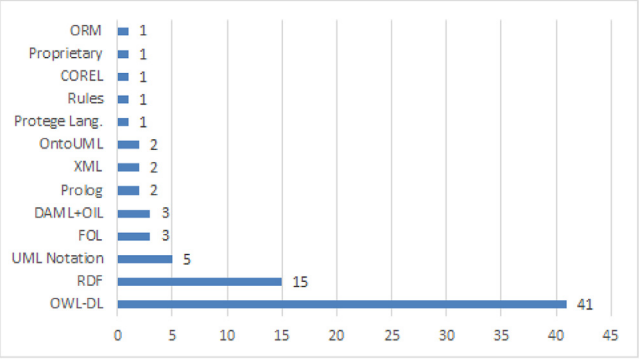

Fig. 12. Formalization standards.

domain is the porosity, or open-texture (Bagby & Mullen, 2007; Breuker et al., 2002; Ceci & Gangemi, 2016; Gangemi et al., 2003; Ghosh et al., 2017; Nadah et al., 2007; Valente et al., 1999; Zhang, Pu, & Wang, 2015).

Inaccurate Modeling emerges as an anomaly concerning conceptual confusion, usually stemming from linguistic jargon and intrinsically rich language (Ajani et al., 2016; Antunes et al., 2014; Freitas et al., 2011; Mommers, 2003). Inconsistencies are situations that present contradictory definitions, or categories of elements that cannot be instantiated (Ajani et al., 2016; Barabucci et al., 2013; Ceci & Gangemi, 2016; Freitas et al., 2011; Rodrigues et al., 2015). For additional information, check Appendix A.

3.2.8. Ontology formalization

Through an ontological representation, codes, decrees, cases, and all sorts of regulations may be formalized in a machine-readable fashion to support decision-making in the legal domain. Research question **RQ10** sought to determine the main formalisms used, whose result is outlined in Fig. 12.

The open Semantic Web standards (the **Ontology Web Language** (OWL) and the **Resource Description Framework** (RDF) triples have been widely used. It may be argued that, following the design of this new knowledge-sharing web, its underlying patterns have defined a mutually beneficial relationship with respect to the ontologies, in a scenario where one encourages and promotes improvements in the other.

As a general-purpose modeling language in the field of software engineering, **UML** class and object diagrams have been used to create (lightweight) ontology taxonomies (Ajani et al., 2016; Baumann & Loës, 2010; Breaux & Powers, 2009; Brighi, 2004) through association and inheritance relationships. UML has been also complemented with first order assertions (**FOL**) to axiomatize the domain (Gangemi et al., 2003). An ontologically well-founded extension of UML, **OntoUML**, is a proposal strongly grounded on the Unified Foundational Ontology, which was used to redraw a portion of the UML 2.0 metamodel to specifically address conceptual modeling. OntoUML (Griffo et al., 2016; Machado & Oliveira, 2014) is used to the treat relationships with the civil law system and legal standards-relations, such as rights-duties.

Earlier studies (Breuker et al., 2002; Corcho et al., 2005; Delgado et al., 2003) were based on an older semantic markup language for web resources: the **DAML+OIL** language. Some ontologies were built on **Rule formalisms** (Hoekstra et al., 2009), dressed as meta-information to control reasoning tasks. Clauses of the declarative logical language **Prolog**, for example, were used for this purpose (Shaheed et al., 2005; van Kralingen et al., 1999). In this set of formalisms, the **eXtensible Markup Language (XML)** also played an important role in organizing legal documents from different perspectives: structural, textual, and metadata (Barabucci et al., 2010; Saravanan et al., 2009).

Other lesser known formalisms have also been identified. Jarrar et al. (2003) captures the core knowledge of the customer complaint domain through the conceptual graphical **Object-Role Modeling (ORM) notation**; de Gracia Carrión Delgado (2015) builds an ontology for criminal offences on top of the **COnceptual REpresentation Language, COREL**; and Lovrencic and Tomac (2006) conceptualized an ontology for the Family Legislation Act comprising individual interpretations based on the **Protégé Axiom Language, PAL**.

4. General discussion

In the course of this process, it was possible to raise some insights, which helped to guide the study and identify gaps that still require further investigation.

4.1. Threats of validity

Although we have strictly followed the systematic mapping process, some factors may threaten the validity of the study, especially the formulation of the search string, the coverage of the research, and the data extraction process.

We are aware that terms such as “conceptual models” or “semantic models” can be exceptionally used as synonyms for ontologies. However, to improve the accuracy of the search, a primitive search string has been refined through some interactions. We have therefore decided to use only the standard term “Ontology”, because it was possible to obtain a greater number of relevant articles, without undermining the search with an excessive number of irrelevant studies.

Kitchenham, Budgen, and Brereton (2010) point out that SMS do not need to retrieve all available studies, because its focus is to identify trends and topics covered in the literature. A good sample is preferred, although it may be somewhat difficult to evaluate (Wohlin et al., 2013). We seek to ameliorate this problem by performing the search in seven different databases.

Reviewers performed the data extraction process independently, so that one did not interfere in the other's work at first. In the end, the data were compared, and cases of doubts were resolved with the help of a third reviewer.

4.2. The maturity of the field

It is noteworthy that the advent of the Semantic Web is in close harmony with ontological engineering, also extended to legal models. In the graph of publications by year, it is possible to observe a vertiginous increase of legal ontologies in the 2000s, indicating that a correlation may exist (although there is no statistical evidence). Likewise, this subject area has already been well-accepted in renowned congresses and journals, demonstrating that it is a scientifically mature research field within AI & Law.

Something little explored, however, are the limits of semantic web standards in the conceptualization of the legal domain. Although the juridical realm is an opportune landscape for Semantic Web applications, it should be noted that classical logic, which is the basis of Description Logic, does not fit fully into all juridical nuances. Legal reasoning is, in principle, defeasible (Winkels et al., 2010). Exceptions and restrictions make the domain challenging and formalizing the juridical domain exclusively by a monotonic logic is an onerous and labor-intensive task. Even if a situation can be modelled monotonically, the approach may appear unnatural and hard to understand by non-logicians. Among the selected primary studies, Barabucci et al. (2010), Bruckschen et al. (2010), Gangemi et al. (2003) and Hage and Verheij (1999) have argued about the need for the development of flexible fine-grained logical representations (such as defeasible logics) that are able to handle

conflict resolution (Ajani et al., 2016) and argumentation schemes (Ceci & Gangemi, 2016; Wyner & Hoekstra, 2012) (which use defeasible reasoning as well).

4.3. The purpose of the ontology

It was observed that legal ontologies are usually built for specific problems or situations. This is a conclusion reached from the classification of the ontologies by the purposes for which they were engineered. At one end, "Reasoning and Problem Solving" accounted for 41% of studies, while on the other, only 12% focused on "Understanding the domain". The latter is the purpose most closely linked to the construction of general core-ontologies.

Particularly w.r.t. types of legal reasoning, some countries with Anglo-Saxon influence (United States of America, England, among others) follow the Common Law paradigm, where situations are judged primarily by similar precedent cases (known as Jurisprudence). Other countries (such as Brazil, Portugal, Spain, Italy) use the Civil Law, where judgments are based on the written laws. That said, it was observed that studies focusing on case-based reasoning have been almost exclusively linked to the purpose of "Semantic Indexing and Search" (Saravanan et al., 2009; Tantisripreecha & Soonthornphisaj, 2011; van Laarschot et al., 2005; Wyner & Hoekstra, 2012; Zhang et al., 2015). Conversely, studies addressing Civil Law were equally scattered across all purposes.

4.4. Legal theories

The bubble chart addressing legal theories attests to the concentration of studies around positive legal theories (represented by the theories of Hohfeld, Hart and Kelsen). There are 44 studies that meet this requirement, or approximately 56% of all studies (this ratio becomes even more lopsided, 88% of the total, when considering only those studies dealing with some legal theory). These older theories are fundamental to many legal systems around the world, because they shape the norms, their deontic qualifications (prohibition, permission, obligation), and their functions (regulatory norms, meta norms, among others). It is said, therefore, that positive theories are intertwined with the normative perspective of the legal order.

Positive theories, however, as claimed by Kelsen (Marmor, 2016), are pure and anti-ideological, that is, they have a purely descriptive conception. Contemporary theories today recognize the need for legal sciences to also consider social values, materialized through doctrines and principles. The current understanding is the Law cannot be treated as something finished and complete, but subject to constant modifications. Relating this to Fig. 4, there is a huge abyss to be overcome considering the ontological conceptualization of contemporary theories (in the graph, represented by Alexy's theory).

More than a third of the studies (36%) did not bother to align the ontology to any legal philosophical basis. This is a high percentage, considering that the proposals presented in these studies were linked to very specific goals, impairing their reusability, as well as making them subject to conceptual confusions, mistaken assumption, and bad modeling.

4.5. Ontology types

Regarding the generalization level, core and domain ontologies were the most commonly used types (46% and 51% of total primary studies, respectively). With regard to core ontologies, many studies looked for domain-generic model, not engineered upon a specific legal subject in order to represent the dimension and heterogeneity of the legal domain, and serve as an intermediate representation between higher-level philosophical theories and legal theories. With regard to domain ontologies, the selected studies had a more practical objective, that is, to conceptualize legal knowledge in its most diverse forms and formalize it in semantically annotated standards.

Despite the numerous efforts to produce higher-level legal ontologies, domain ontologies were almost always based on other top ontologies (such as DOLCE, UFO, among others), other than the LKIF/LRI core ontology. This underscores the need to understand the causes of this situation (for example, if top legal ontologies do not faithfully serve the purposes of the underlying legal theories) in order to reverse this scenario. One proposal, for example, would be to look at a general theory of crime as a core ontology, leaving the specific criminal types to be handled by the domain ontologies.

4.6. Legal domains

A trend in ontological development can be noted, driven by contractual-commercial, criminal, privacy and intellectual property issues. Together, these constitute cross-border legal concerns, which helps to explain the number of publications. Each of these sub-domains can, however, unfold into even smaller categories. For example, some criminal sub types were identified in the mapping, such as crimes involving abuse of alcohol while driving (Rodrigues et al., 2015), crimes against property (Rodrigues et al., 2016), and terrorism (Zarri, 2007). However, the criminal code contains a large number of criminal sub-types (crimes of corruption, extortion, crimes against life) that need further attention.

Even after a few decades of research in the area, it is well-known that other areas are still open. Taking into account the current reality in many countries, it is important to mention the laws that govern environmental issues (agricultural and environmental law), laws that dictate basic human needs (housing law), and laws involving principles of governance (electoral law).

Through a broader view, it was also possible to analyze the sources of Law mapped. Norms and cases have been highlighted in the surveys over the years. In addition, some studies focused on a joint study of these, as in the proposed circular ontology (Zhang et al., 2015). There is, however, a need to investigate other sources, such as doctrines and principles. Moreover, it should be pointed out that, in the practical context, these complement each other, closing possible unseen situations, such as the relation between the crimes against the property and the "Trifle principle"(Samuels, 1985), which removes any criminal liability if, in a potential robbery crime, the subtracted good is of irrelevant value. We believe that by adopting other principles, such as those governing spatio-temporal peculiarities, we further tighten up the Law with decision support systems.

4.7. Engineering methods

Considering the ontological engineering process, the vast majority (93.5%) of legal ontology development occurred manually. Much still needs to be studied in terms of identification, extraction, and automatic construction of legal ontologies. Automation is essential given the vast scope and dimension of the legal corpus.

The methodologies employed are those commonly used in the development of ontologies in general, with emphasis on the traditional Methontology and Ontology Development 101. Competence questions have also been shown to be a regular strategy for requirement specification. A path open for research is that of investigating the appropriateness of methodologies and good-practices for different sources of legal knowledge. For example, it is questioned whether ontological engineering for normative information will behave the same as that for knowledge based on previous cases or the tacit knowledge of specialists in the field. For the latter, the participation of experts becomes even more crucial. For the

reasoning model based on jurisprudence, the ontological evaluation should be done based on a set of cases and their respective inferences. Normative knowledge may, however, require a much more rigorous theoretical basis. All of this can impact development models.

Though top-down and bottom-up building strategies have been the principal choices, something unusual was observed. In Ceci and Gangemi (2016) and Ghosh et al. (2017), the "hybrid" and "middle-out" approaches have been misused as synonyms. Unlike the hybrid approach, for the middle-out method "[...] *it is stressed that the most basic terms in each cluster should be defined before moving on to more abstract and more specific terms within a cluster*" (Hoekstra et al., 2009). Therefore, while nine studies contemplated the combined top-down and bottom-up strategies, only two studies strictly followed the middle-out approach. It is suggested, then, that another future study be to analyze the result produced by this last approach w.r.t. the previous ones.

4.8. Evaluation techniques

Among the investigations carried out, ontological evaluation is still perhaps the weakest point. Forty-one percent (41%) of studies did not show any ontological verification or validation activity. The inherent difficulties of the domain require the presence of specialists at the model design phase to avoid errors that will be propagated throughout the entire project. Unfortunately, only a bare minimum (3.8%) were observed to have this support available. The positive point of the classification was to identify the advantages in conceptualizing domains rooted in higher-level ontologies which already accommodated a profile that improves conceptual modeling. Misconceptions can thus be found in advance, and potentially fixed.

4.9. Legal nuances and anomalies

The particularities (and the resulting anomalies) show how much challenging the legal domain is from the point of view of knowledge representation and reasoning. Nevertheless, linguistic problems should be addressed by formalizing the domain terminology in terms of a formally-specified ontology. Content is described by the use of a well-grounded knowledge representation formalism rooted in logical-mathematical terms. Therefore, the concept definition may assume well-defined semantics, which reduces ambiguities of interpretation, though these may still exist in modeling. Another advantage of providing a logically-formalized model is to perform automatic reasoning and find out if concepts may be rearranged in a subsumption relationship or if a group of definitions lacks consistency.

For future study, it is possible to investigate the adoption of defeasible logic to accommodate conflicts between the written rules and the legal principles, such as the crimes against the property and the "Trifle Principle" (Samuels, 1985).

4.10. The standards for legal ontologies

A strong indication of the close relationship between the Semantic Web and the engineering of legal ontologies could be observed from the result of the questioning about the formal standards adopted. The RDF/OWL pair (Semantic Web architecture base) was used in more than half of the primary studies. It is an important finding as it is uncommon in other known domains for a considerable number of formalized ontologies to exist.

5. Conclusion and ongoing studies

Finally, it is worth mentioning that the goal proposed by this SMS was successfully fulfilled. Through the research questions, it was possible to elaborate a classification scheme identifying the general context of what has been produced, the shortcomings, and the real possibilities of future study. It should also be emphasized that the results achieved encourage other deeper systematic reviews. Moreover, the retrieved ontologies may be widely used as a knowledge base of expert systems for simulation of legal actions.

Among the likely lines of research mentioned, two related projects are already under way. An ongoing study compares classical description logic with a kind of non-monotonic description logic for representing legal domains. In particular, the study shows how the Preferential Description Logic (Britz, Meyer, & Varzinczak, 2011) is more suited than classical DL for a faithful representation of the content of legal regulatory knowledge, when dealing with exceptions. A second project describes a new core legal ontology, built top-down from the UFO upper-level ontology, engineered using the positivist legal theory of Hans Kelsen, fostering reusability across a plurality of the criminal field. In especial, this study was conducted to further highlight the depiction of Crimes of Omission, which have not yet been explored.

Credit authorship contribution statement

Cleyton Mário de Oliveira Rodrigues: Investigation, Conceptualization, Methodology, Validation, Writing - original draft , Writing - review & editing. **Frederico Luiz Gonçalves de Freitas:** Supervision, Funding acquisition. **Emanoel Francisco Spósito Barreiros:** Validation, Writing - original draft, Writing - review & editing. **Ryan Ribeiro de Azevedo:** Methodology, Investigation. **Adauto Trigueiro de Almeida Filho:** Resources, Visualization, Writing - review & editing.

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Appendix A. Classification of studies

Studies by engineering approach:

- **Top-Down**: Rodrigues et al. (2015), Lehmann et al. (2004), Saravanan et al. (2009), Boella et al. (2004), Panagiotopoulos et al. (2011), Gangemi et al. (2003), Machado and Oliveira (2014), Griffo et al. (2016), van de Ven et al. (2008), Cernian et al. (2013), Gostojic et al. (2013), Breuker et al. (2002);
- **Bottom-Up**: Nadah et al. (2007), Brighi (2004), Mittal et al. (2016), Bruckschen et al. (2010), Adams (2008), Costilla et al. (2005), Bagby and Mullen (2007), Bartolini et al. (2017), Zhang et al. (2015), Salam (2007), Ajani et al. (2016), Mimouni (2013), Cappelli et al. (2007), Casellas et al. (2010);
- **Hybrid**: Casellas et al. (2007), Rodrigues et al. (2016), Sagri and Tiscornia (2003), Valente et al. (1999), Ghosh et al. (2017), Agnoloni and Tiscornia (2010), Ceci and Gangemi (2016), Distinto et al. (2016), Tiscornia (2006);
- **Middle-out**: Hoekstra et al. (2009), Bui et al. (2014).

Studies by country:

- **Australia**: Abrahams et al. (2011);
- **Belgium**: Jarrar et al. (2003);
- **Brazil**: Rodrigues et al. (2015), Freitas et al. (2011), Rodrigues et al. (2016), Bruckschen et al. (2010), Drumond and Girardi (2008), Machado and Oliveira (2014), Griffo et al. (2016);

- **Canada**: Adams (2008);
- **China**: Lu et al. (2012), Zhang et al. (2015);
- **Croatia**: Lovrencic and Tomac (2006);
- **France**: Nadah et al. (2007), Ghosh et al. (2017), Zarri (2007), Mimouni (2013);
- **Germany**: Baumann and Loës (2010);
- **Greece**: Panagiotopoulos et al. (2011);
- **Japan**: Kurematsu and Yamaguchi (1997), Lu and Ikeda (2008);
- **India**: Saravanan et al. (2009), Shankhdhar and Darbari (2015);
- **Italy**: Barabucci et al. (2013), Brighi (2004), Sagri and Tiscornia (2003), Tiscomia (2001), Lehmann et al. (2004), Cevenini et al. (2008), Barabucci et al. (2010), Boella et al. (2004), Agnoloni and Tiscornia (2010), Gangemi et al. (2003), Ceci and Gangemi (2016), Rubino et al. (2006), Ajani et al. (2016), Distinto et al. (2016), Cappelli et al. (2007), Tiscornia (2006);
- **Korea**: Lee et al. (2011), Jinhyung et al. (2012);
- **Luxembourg**: Bartolini et al. (2017);
- **Poland**: Stolarski and Tomaszewski (2008);
- **Portugal**: Antunes et al. (2014);
- **Romania**: Cornoiu and Valean (2015), Cernian et al. (2013);
- **Serbia**: Gostojic et al. (2013);
- **Spain**: Casellas et al. (2007), de Gracia Carrión Delgado (2015), Mitre et al. (2006), Corcho et al. (2005), Costilla et al. (2005), Gómez-Pérez et al. (2006), Delgado et al. (2003), Casellas et al. (2010), Rodríguez-Doncel et al. (2014), Buey et al. (2016);
- **Taiwan**: Hu et al. (2011);
- **Thailand**: Tantisripreecha and Soonthornphisaj (2011), Boonchom and Soonthornphisaj (2012);
- **The Netherlands**: Mommers (2003), Hoekstra et al. (2009), Winkels et al. (2010), van Kralingen et al. (1999), Hage and Verheij (1999), van Laarschot et al. (2005), Breuker and Hoekstra (2004a), van de Ven et al. (2008), Breuker et al. (2002);
- **UK**: Wyner and Hoekstra (2012), Shaheed et al. (2005);
- **USA**: Mittal et al. (2016), Breaux and Powers (2009), Valente et al. (1999), Bagby and Mullen (2007), Salam (2007), McClure (2007);
- **Vietnam**: Bui et al. (2014).

Studies by standards:

- **OWL-DL**: Rodrigues et al. (2015), Barabucci et al. (2013), Hoekstra et al. (2009), Winkels et al. (2010), Freitas et al. (2011), Abrahams et al. (2011), Brighi (2004), Rodrigues et al. (2016), Mittal et al. (2016), Cornoiu and Valean (2015), Ghosh et al. (2017), Bruckschen et al. (2010), van Laarschot et al. (2005), Wyner and Hoekstra (2012), Mitre et al. (2006), Drumond and Girardi (2008), Adams (2008), Lu et al. (2012), Corcho et al. (2005), Cevenini et al. (2008), Costilla et al. (2005), Bagby and Mullen (2007), Gómez-Pérez et al. (2006), Stolarski and Tomaszewski (2008), Agnoloni and Tiscornia (2010), Panagiotopoulos et al. (2011), Bartolini et al. (2017), Antunes et al. (2014), Lu and Ikeda (2008), Rubino et al. (2006) Breuker and Hoekstra (2004a), Salam (2007), Jinhyung et al. (2012), van de Ven et al. (2008), Shankhdhar and Darbari (2015), Distinto et al. (2016), Mimouni (2013), Gostojic et al. (2013), Casellas et al. (2010), Rodríguez-Doncel et al. (2014);
- **RDF**: Barabucci et al. (2013), Casellas et al. (2007), Freitas et al. (2011), Brighi (2004), Mittal et al. (2016), Lee et al. (2011), Corcho et al. (2005), Agnoloni and Tiscornia (2010), Shankhdhar and Darbari (2015), Mimouni (2013), Cernian et al. (2013), Breuker et al. (2002), Rodríguez-Doncel et al. (2014), McClure (2007);
- **UML Notation**: Baumann and Loës (2010), Brighi (2004), Breaux and Powers (2009), Gangemi et al. (2003), Ajani et al. (2016);
- **First-Order Logic**: Hage and Verheij (1999), Zarri (2007), Gangemi et al. (2003);
- **DAML+OIL**:Corcho et al. (2005), Delgado et al. (2003), Breuker et al. (2002);
- **OntoUML**: Machado and Oliveira (2014), Griffo et al. (2016);
- **Prolog Style Rules**: van Kralingen et al. (1999), Shaheed et al. (2005);
- **XML**: Saravanan et al. (2009), Barabucci et al. (2010) ;
- **Rule Formalism**: Hoekstra et al. (2009);
- **Protg Axiom Language**: Lovrencic and Tomac (2006);
- **COREL**: de Gracia Carrión Delgado (2015);
- **ORM**: Jarrar et al. (2003);
- **Proprietary Notation**: Boella et al. (2004).

Studies by venue:

- **Book**: Corcho et al. (2005), Costilla et al. (2005), Barabucci et al. (2010), Gangemi et al. (2003);
- **Journal**: Freitas et al. (2011), van Kralingen et al. (1999) Valente et al. (1999), Hage and Verheij (1999), Wyner and Hoekstra (2012), Kurematsu and Yamaguchi (1997), Drumond and Girardi (2008), Adams (2008), Lehmann et al. (2004), Saravanan et al. (2009), Bagby and Mullen (2007), Boella et al. (2004), Zarri (2007), Lu et al. (2012) Panagiotopoulos et al. (2011), Tantisripreecha and Soonthornphisaj (2011), Lu and Ikeda (2008), Boonchom and Soonthornphisaj (2012), Ceci and Gangemi (2016), Distinto et al. (2016), Ajani et al. (2016), Jinhyung et al. (2012), Shankhdhar and Darbari (2015), Cernian et al. (2013), Gostojic et al. (2013);
- **Conference**: Rodrigues et al. (2015), Mommers (2003), Baumann and Loës (2010), Barabucci et al. (2013), Nadah et al. (2007), Hoekstra et al. (2009), Winkels et al. (2010), Casellas et al. (2007), Abrahams et al. (2011), Rodrigues et al. (2016), Mittal et al. (2016), Breaux and Powers (2009), Cornoiu and Valean (2015), Lovrencic and Tomac (2006), Lee et al. (2011), de Gracia Carrión Delgado (2015), Ghosh et al. (2017), van Laarschot et al. (2005), Cevenini et al. (2008), Gómez-Pérez et al. (2006), Stolarski and Tomaszewski (2008), Agnoloni and Tiscornia (2010), Hu et al. (2011), Bui et al. (2014), Bartolini et al. (2017), Antunes et al. (2014), Griffo et al. (2016), Zhang et al. (2015), Breuker and Hoekstra (2004a), Salam (2007), Delgado et al. (2003), van de Ven et al. (2008), Mimouni (2013), Casellas et al. (2010), Breuker et al. (2002), Buey et al. (2016);
- **Workshop**: Brighi (2004), Sagri and Tiscornia (2003), Tiscomia (2001), Bruckschen et al. (2010), Mitre et al. (2006), Jarrar et al. (2003), Machado and Oliveira (2014), Shaheed et al. (2005), Rubino et al. (2006), Cappelli et al. (2007), Rodríguez-Doncel et al. (2014), McClure (2007), Tiscornia (2006).

Studies by legal theory:

- **Kelsen**: Rodrigues et al. (2015), Baumann and Loës (2010), Hoekstra et al. (2009), Winkels et al. (2010), Casellas et al. (2007), Rodrigues et al. (2016), Breaux and Powers (2009), Sagri and Tiscornia (2003), Tiscomia (2001), van Kralingen et al. (1999), Valente et al. (1999), Hage and Verheij (1999), Ghosh et al. (2017), Mitre et al. (2006), Zarri (2007), Panagiotopoulos et al. (2011), Bui et al. (2014), Gangemi et al. (2003), Machado and Oliveira (2014), Ceci and Gangemi (2016), Rubino et al. (2006), Breuker and Hoekstra (2004a), Salam (2007), van de Ven et al. (2008),

Distinto et al. (2016), Gostojic et al. (2013), Breuker et al. (2002), Tiscornia (2006);
- **Hart**: Rodrigues et al. (2015), Hoekstra et al. (2009), Winkels et al. (2010), Brighi (2004), Rodrigues et al. (2016), Lovrencic and Tomac (2006), Sagri and Tiscornia (2003), Lee et al. (2011), Tiscomia (2001), Valente et al. (1999), Lehmann et al. (2004), Costilla et al. (2005), Stolarski and Tomaszewski (2008), Boella et al. (2004), Hu et al. (2011), Tantisripreecha and Soonthornphisaj (2011), Bui et al. (2014), Gangemi et al. (2003), Ceci and Gangemi (2016), van de Ven et al. (2008), Mimouni (2013), Tiscornia (2006);
- **Hohfeldian**: Breaux and Powers (2009), Sagri and Tiscornia (2003), Tiscomia (2001), Kurematsu and Yamaguchi (1997), Mitre et al. (2006), Saravanan et al. (2009), Boella et al. (2004), Bartolini et al. (2017), Gangemi et al. (2003), Shaheed et al. (2005), Ceci and Gangemi (2016), Rubino et al. (2006), Boonchom and Soonthornphisaj (2012), Gostojic et al. (2013), Rodríguez-Doncel et al. (2014), Tiscornia (2006);
- **Negotiation**: Abrahams et al. (2011), van Laarschot et al. (2005), Delgado et al. (2003);
- **Intentional**: Lu et al. (2012), Lu and Ikeda (2008);
- **Alexy**: Griffo et al. (2016);
- **Speech-Acts**: van Kralingen et al. (1999);
- **Undefined**: Mommers (2003), Barabucci et al. (2013), Nadah et al. (2007), Freitas et al. (2011), McClure (2007), Mittal et al. (2016), Cornoiu and Valean (2015), de Gracia Carrión Delgado (2015), Bruckschen et al. (2010), Wyner and Hoekstra (2012), Drumond and Girardi (2008), Adams (2008), Corcho et al. (2005), Cevenini et al. (2008), Bagby and Mullen (2007), Gómez-Pérez et al. (2006), Barabucci et al. (2010), Jarrar et al. (2003), Antunes et al. (2014), Zhang et al. (2015), Ajani et al. (2016), Jinhyung et al. (2012), Shankhdhar and Darbari (2015), Cappelli et al. (2007), Cernian et al. (2013), Casellas et al. (2010), Buey et al. (2016).

Studies by Anomaly Source:

- **Dynamicity**: Cornoiu and Valean (2015), Hage and Verheij (1999), Ceci and Gangemi (2016), Cernian et al. (2013);
- **Volume of Data**: Mittal et al. (2016), Cornoiu and Valean (2015), Tiscomia (2001), Saravanan et al. (2009), Gómez-Pérez et al. (2006), Tantisripreecha and Soonthornphisaj (2011), Bui et al. (2014), Lu and Ikeda (2008), Jinhyung et al. (2012), van de Ven et al. (2008), Cernian et al. (2013), Casellas et al. (2010);
- **Legal Jargon**: Rodrigues et al. (2015), Mittal et al. (2016), Costilla et al. (2005), Saravanan et al. (2009), Ajani et al. (2016);
- **Source Heterogeneity**: Rodrigues et al. (2015), Barabucci et al. (2013), Rodrigues et al. (2016), Sagri and Tiscornia (2003), van Laarschot et al. (2005), Adams (2008), Costilla et al. (2005), Panagiotopoulos et al. (2011), Machado and Oliveira (2014), Jinhyung et al. (2012), Shankhdhar and Darbari (2015), Distinto et al. (2016), Buey et al. (2016);
- **Overlapping Jurisdiction** Winkels et al. (2010), Lu et al. (2012), Jarrar et al. (2003), Agnoloni and Tiscornia (2010), Hu et al. (2011), Ajani et al. (2016).

Studies by Ontology Purpose:

- **Organizing/Structuring**: Sagri and Tiscornia (2003), de Gracia Carrión Delgado (2015), Bruckschen et al. (2010), Kurematsu and Yamaguchi (1997), Costilla et al. (2005), Gómez-Pérez et al. (2006), Stolarski and Tomaszewski (2008), Barabucci et al. (2010), Jarrar et al. (2003), Antunes et al. (2014), Rubino et al. (2006), Ajani et al. (2016), Jinhyung et al. (2012), Distinto et al. (2016), Tiscornia (2006);
- **Reasoning/Solving**: Rodrigues et al. (2015), Baumann and Loës (2010), Nadah et al. (2007), Winkels et al. (2010), Freitas et al. (2011), Abrahams et al. (2011), Rodrigues et al. (2016), Mittal et al. (2016), Breaux and Powers (2009), Lovrencic and Tomac (2006), van Kralingen et al. (1999), Hage and Verheij (1999), Ghosh et al. (2017), van Laarschot et al. (2005), Wyner and Hoekstra (2012), Mitre et al. (2006), Drumond and Girardi (2008), Corcho et al. (2005), Lehmann et al. (2004), Bagby and Mullen (2007), Stolarski and Tomaszewski (2008), Zarri (2007), Hu et al. (2011), Gangemi et al. (2003), Antunes et al. (2014), Shaheed et al. (2005), Ceci and Gangemi (2016), Salam (2007), Jinhyung et al. (2012), van de Ven et al. (2008), Casellas et al. (2010), Rodríguez-Doncel et al. (2014);
- **Indexing/Search**: Casellas et al. (2007), Brighi (2004), Cornoiu and Valean (2015), Tiscomia (2001), van Laarschot et al. (2005), Wyner and Hoekstra (2012), Cevenini et al. (2008), Saravanan et al. (2009), Gómez-Pérez et al. (2006), Zarri (2007), Tantisripreecha and Soonthornphisaj (2011), Bui et al. (2014), Zhang et al. (2015), Boonchom and Soonthornphisaj (2012), Delgado et al. (2003), Shankhdhar and Darbari (2015), Distinto et al. (2016), Mimouni (2013), Cappelli et al. (2007), Cernian et al. (2013), Gostojic et al. (2013), Breuker et al. (2002), Buey et al. (2016), Tiscornia (2006);
- **Semantic Integration/ Interoperation**: Barabucci et al. (2013), Nadah et al. (2007), Lu et al. (2012), Cevenini et al. (2008), Jarrar et al. (2003), Agnoloni and Tiscornia (2010), Hu et al. (2011), Panagiotopoulos et al. (2011), Bartolini et al. (2017), Lu and Ikeda (2008), Delgado et al. (2003), Distinto et al. (2016), McClure (2007);
- **Understanding the Domain**: Mommers (2003), Hoekstra et al. (2009), Lee et al. (2011), Valente et al. (1999), Adams (2008), Boella et al. (2004), Machado and Oliveira (2014), Griffo et al. (2016), Breuker and Hoekstra (2004a).

Studies by Generalization Level:

- **Top**: Breaux and Powers (2009), Hage and Verheij (1999), Lehmann et al. (2004), Zarri (2007), Shaheed et al. (2005);
- **Core**: Mommers (2003), Barabucci et al. (2013), Hoekstra et al. (2009), Casellas et al. (2007), Brighi (2004), Cornoiu and Valean (2015), Sagri and Tiscornia (2003), Lee et al. (2011), Tiscomia (2001), van Kralingen et al. (1999), de Gracia Carrión Delgado (2015), Valente et al. (1999), Kurematsu and Yamaguchi (1997), Drumond and Girardi (2008), Corcho et al. (2005), Costilla et al. (2005), Barabucci et al. (2010), Boella et al. (2004), Panagiotopoulos et al. (2011), Tantisripreecha and Soonthornphisaj (2011), Bui et al. (2014), Gangemi et al. (2003), Machado and Oliveira (2014), Griffo et al. (2016), Zhang et al. (2015), Rubino et al. (2006), Breuker and Hoekstra (2004a), Ajani et al. (2016), Jinhyung et al. (2012), Shankhdhar and Darbari (2015), Distinto et al. (2016) Mimouni (2013), Cernian et al. (2013), Gostojic et al. (2013), Buey et al. (2016), McClure (2007);
- **Domain**: Rodrigues et al. (2015), Baumann and Loës (2010), Nadah et al. (2007), Winkels et al. (2010), Freitas et al. (2011), Abrahams et al. (2011), Rodrigues et al. (2016), Mittal et al. (2016), Lovrencic and Tomac (2006), Tiscomia (2001), van Kralingen et al. (1999), Ghosh et al. (2017), Bruckschen et al. (2010), van Laarschot et al. (2005), Kurematsu and Yamaguchi (1997), Mitre et al. (2006), Adams (2008), Lu et al. (2012), Cevenini et al. (2008), Saravanan et al. (2009), Bagby and Mullen (2007), Gómez-Pérez et al. (2006), Stolarski and Tomaszewski (2008), Jarrar et al. (2003), Agnoloni and Tiscornia (2010),

Hu et al. (2011), Bartolini et al. (2017), Antunes et al. (2014), Lu and Ikeda (2008), Ceci and Gangemi (2016), Boonchom and Soonthornphisaj (2012), Salam (2007), Delgado et al. (2003), van de Ven et al. (2008), Shankhdhar and Darbari (2015), Cappelli et al. (2007), Casellas et al. (2010), Breuker et al. (2002), Rodríguez-Doncel et al. (2014), Tiscornia (2006);
- **Application**: Wyner and Hoekstra (2012).

Studies by Legal Subdomain:

- **Criminal**: Rodrigues et al. (2015) Rodrigues et al. (2016), Ghosh et al. (2017), van Laarschot et al. (2005), Shankhdhar and Darbari (2015), Breuker et al. (2002);
- **Civil**: Abrahams et al. (2011);
- **License**: Baumann and Loës (2010), Nadah et al. (2007), Adams (2008), Lu et al. (2012), Cevenini et al. (2008), Antunes et al. (2014), Lu and Ikeda (2008), Delgado et al. (2003);
- **Succession**: Lovrencic and Tomac (2006), Boonchom and Soonthornphisaj (2012);
- **Traffic**: Freitas et al. (2011);
- **Contract**: Mittal et al. (2016), Kurematsu and Yamaguchi (1997), Gómez-Pérez et al. (2006), Salam (2007), van de Ven et al. (2008);
- **Tax**: Saravanan et al. (2009);
- **Consumer**: Jarrar et al. (2003), Agnoloni and Tiscornia (2010), Ceci and Gangemi (2016), Rodríguez-Doncel et al. (2014), Tiscornia (2006);
- **Local Government**: Winkels et al. (2010);
- Privacy: Tiscomia (2001), Bruckschen et al. (2010), Mitre et al. (2006), Hu et al. (2011), Bartolini et al. (2017), Cappelli et al. (2007), Casellas et al. (2010);
- **Labor**: van Kralingen et al. (1999);
- **Commercial**: Bagby and Mullen (2007), Stolarski and Tomaszewski (2008).

Studies by Methodology:

- **Requirements Specification**: Panagiotopoulos et al. (2011), Bartolini et al. (2017), Casellas et al. (2010), Rodríguez-Doncel et al. (2014);
- **Methontology**: Rodrigues et al. (2015), Corcho et al. (2005), Gómez-Pérez et al. (2006), Stolarski and Tomaszewski (2008);
- **Ontology Development 101**: Cevenini et al. (2008), Zarri (2007), Cernian et al. (2013)
- **TERMINAE**: Mitre et al. (2006), Saravanan et al. (2009) ;
- **CommonKADS**: van Kralingen et al. (1999), Valente et al. (1999);
- **Dogma**: Jarrar et al. (2003);
- **Diligent**: Casellas et al. (2007);
- **COHERENT**: de Gracia Carrión Delgado (2015);
- **Hoekstra Guidelines**: Wyner and Hoekstra (2012);
- **Valente/Breuker Principles**: Adams (2008);
- **Horridge Guidelines**: Antunes et al. (2014);
- **Ontology Design Patterns/Neon Project**: Barabucci et al. (2010).

Studies by Evaluation Approach:

- **Specialists**: Casellas et al. (2007), Saravanan et al. (2009), Agnoloni and Tiscornia (2010);
- **Data-Driven**: Baumann and Loës (2010), Bruckschen et al. (2010), van Laarschot et al. (2005), Kurematsu and Yamaguchi (1997), Buey et al. (2016);
- **Gold-Standard**: Barabucci et al. (2013), Hoekstra et al. (2009), Rodrigues et al. (2016), Sagri and Tiscornia (2003), Tiscomia (2001), Ghosh et al. (2017), Wyner and Hoekstra (2012), Boella et al. (2004), Bartolini et al. (2017), Gangemi et al. (2003), Machado and Oliveira (2014), Griffo et al. (2016), Rubino et al. (2006), Breuker and Hoekstra (2004a), Delgado et al. (2003), Gostojic et al. (2013), Tiscornia (2006);
- **Case Study**: Rodrigues et al. (2015), Nadah et al. (2007), Rodrigues et al. (2016), Breaux and Powers (2009), van Kralingen et al. (1999), Valente et al. (1999), Hage and Verheij (1999), Bagby and Mullen (2007), Stolarski and Tomaszewski (2008), Barabucci et al. (2010), Zarri (2007), Jarrar et al. (2003), Bui et al. (2014), Antunes et al. (2014), Machado and Oliveira (2014), Griffo et al. (2016), Shaheed et al. (2005), Lu and Ikeda (2008), Ceci and Gangemi (2016), Salam (2007), Ajani et al. (2016), Distinto et al. (2016), Cappelli et al. (2007), Gostojic et al. (2013), Rodríguez-Doncel et al. (2014);
- **No Evaluation**: Mommers (2003), Winkels et al. (2010), Freitas et al. (2011), Abrahams et al. (2011), Brighi (2004), Mittal et al. (2016), Cornoiu and Valean (2015), Lovrencic and Tomac (2006), Lee et al. (2011), de Gracia Carrión Delgado (2015), Mitre et al. (2006), Drumond and Girardi (2008), Adams (2008), Lu et al. (2012), Corcho et al. (2005), Lehmann et al. (2004), Cevenini et al. (2008), Costilla et al. (2005), Gómez-Pérez et al. (2006), Hu et al. (2011), Panagiotopoulos et al. (2011), Tantisripreecha and Soonthornphisaj (2011), Zhang et al. (2015), Boonchom and Soonthornphisaj (2012) Jinhyung et al. (2012), van de Ven et al. (2008), Shankhdhar and Darbari (2015), Mimouni (2013), Cernian et al. (2013), Casellas et al. (2010), Breuker et al. (2002), McClure (2007).

Syntactic/Semantic Anomalies:

- **Inaccurate Modelling**: Mommers (2003), Freitas et al. (2011), Antunes et al. (2014);
- **Incompleteness**: Valente et al. (1999), Ajani et al. (2016);
- **Inconsistency**: Rodrigues et al. (2015), Barabucci et al. (2013), Freitas et al. (2011), Ceci and Gangemi (2016), Ajani et al. (2016);
- **Cross-Reference**: Breaux and Powers (2009), Lee et al. (2011), van de Ven et al. (2008), Mimouni (2013);
- **Synonym**: Nadah et al. (2007), Casellas et al. (2007), Sagri and Tiscornia (2003), Cevenini et al. (2008), Saravanan et al. (2009), Breuker et al. (2002), Tiscornia (2006);
- **Discrepancy**: Rodrigues et al. (2015), Winkels et al. (2010), Rodrigues et al. (2016), Lovrencic and Tomac (2006), Valente et al. (1999), Stolarski and Tomaszewski (2008), Boella et al. (2004), Hu et al. (2011), Gangemi et al. (2003), Zhang et al. (2015), Ajani et al. (2016), van de Ven et al. (2008), Gostojic et al. (2013);
- **Polysemy**: Nadah et al. (2007), Freitas et al. (2011), Sagri and Tiscornia (2003), Saravanan et al. (2009), Gangemi et al. (2003)Griffo et al. (2016), Ajani et al. (2016), Tiscornia (2006);
- **Open-Textured**: Nadah et al. (2007), Valente et al. (1999), Ghosh et al. (2017), Bagby and Mullen (2007), Gangemi et al. (2003)Zhang et al. (2015), Ceci and Gangemi (2016), Breuker et al. (2002);
- **Vagueness**: Freitas et al. (2011), Rodrigues et al. (2016), Cornoiu and Valean (2015), Lovrencic and Tomac (2006), Ghosh et al. (2017)Lehmann et al. (2004), Saravanan et al. (2009), Ajani et al. (2016), Breuker et al. (2002).

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