Conceptual Modeling and Semantic Web: A Systematic Mapping Study

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Kurzfassung

Konzeptuelle Modellierung strebt an, reale Systeme auf einem höheren Abstraktionsniveau darzustellen. Semantic Web erweitert verschiedenste Datenformate mit Bedeutung und Beziehungen zwischen den Datenelementen, um dadurch zu den so genannten Linked Data zu gelangen. Sowohl konzeptionelle Modellierung als auch Semantic Web helfen dabei, Datenverarbeitung, -darstellung und -integration für Mensch und Maschine zu vereinfachen. Diese Masterarbeit analysiert die Schnittstelle zwischen konzeptioneller Modellierung und Semantic Web mittels einer systematischen Mapping-Studie (SMS). Im Rahmen der SMS wird zunächst deren Umfang definiert, werden sodann einschlägige Suchanfragen ausgeführt und eine Anzahl von anfangs 5107 auf schließlich 484 Publikationen reduziert, deren Metadaten und Volltext extrahiert werden und in die Analysephase einfließen. Die ausgewählten Publikationen werden anhand von zuvor entwickelten Taxonomien klassifiziert. Darauf basierend werden Analysen hinsichtlich bibliografischen, inhaltlichen und kombinierten taxonomiebezogenen Informationen durchgeführt. Zusätzlich werden Research Communities, d.h. Cluster, ermittelt, wobei jeweils deren wissenschaftliche Spezialisierung untersucht wird. Mögliche Einschränkungen der Validität der Ergebnisse sowie Bereiche für zukünftige Forschungsarbeiten in Bezug auf diese Arbeit werden im Hinblick auf die SMS diskutiert.

Abstract

Conceptual models aim to represent real systems at a higher abstraction level. The Semantic Web intends to add meaning to any kind of data formats to arrive at linked data. Taken together, both of them help facilitate data processing and integration for humans as well as for machines. This thesis analyzes the publication landscape at the intersection of conceptual modeling and Semantic Web in the form of a systematic mapping study (SMS). In line with the SMS, the research scope is defined, the search queries are executed, and the publications are screened from an initial number of 5107 to finally 484 papers. Then publications are extracted and mapped according to a series of previously developed taxonomies. The extracted and refined data is analyzed in several analysis steps comprising bibliographical, content, combined taxonomy as well as research community analyses. Threats to validity, and implications for future research from this first SMS regarding the intersection of conceptual modeling and Semantic Web are additionally considered.

Contents

CHAPTER 1

Introduction

Conceptual models are created with the aim to depict a part of a real system in a more abstract way that captures only its essential characteristics [48]. By the means of assumptions, the system is described. The subsequent abstraction process allows for more efficient handling of the underlying excerpt of reality by leaving out unnecessary details. This helps to facilitate communication and sharing of model information between domain experts, managers, developers, and further stakeholders involved in a project [27] [48]. Therefore, conceptual modeling (CM) supports the process of finding clear, suitable, and more consistent shared understanding of the excerpt of the real problem domain than this would be possible without the conceptual model, which could be conveniently extended later on, and could be used as a reference point for verification as well as validation steps [48].

Semantic Web technologies are also geared towards simplification, but in terms of automation of input processing and can be used to formalize underlying representations. Semantic Web (Semantic Web (SW)) systems and technologies use conceptual components like knowledge graphs, vocabularies or ontologies (in varying degrees of formalization) for representation and to enrich systems with further relational meaning and meta data [46]. Since its inception, the Semantic Web has been supported by the World Wide Web Consortium (W3C), which encourages the adoption of common data formats for unstructured data and documents [3]. Within the field of Semantic Web, establishing and making visible the relationships between the underlying data parts is emphasized, which is therefore denoted as “linked data“ that uses Uniform Resource Identifier (URI) to refer to data objects, and is handled in data formats such as Resource Description Framework (RDF) or Resource Description Framework Schema (RDFS) [61] [3].

Taken together, both conceptual modeling and the Semantic Web help to facilitate processing of data objects and data integration for humans as well as for machines. This thesis aims to explore exactly this intersection of conceptual modeling and Semantic Web, and how they can mutually benefit from each other. For this reason, a

Systematic Mapping Study (SMS) is conducted so that the publication landscape at the intersection of the two topics can be depicted in a broader sense. Based on the classified data, a web knowledge base is created so that researchers and readers can explore the publications in the field according to their interests across the taxonomies. The SMS intends to filter out relevant publications along specific criteria, and classify those publications according to taxonomies related to characteristics of the research fields in a systematic way [47]. In doing so, the SMS gives an overview on what kind of research is published at the intersection of the topics, which research communities are standing out, and which focus has been chosen so far compared to research niches that have not been considered much yet [47].

As for the structure of this thesis, the chapter *Motivation and Problem Statement* 2 presents the motivation for this piece of work, and the research fields subject to analysis as well as how they intersect. It closes with the problem statement which points out what topics emerge at the intersection of both conceptual modeling and Semantic Web.

In the chapter *Related Work*, existing systematic mapping studies and systematic literature studies on either conceptual modeling, Semantic Web, or the intersection of both are examined with regard to their research findings, recommendations for further research, and contributions. The research gap that should be filled by this thesis is pointed out and explained.

In the chapter *Research Questions and Methods* 4, the research questions (RQ) that should be answered in line with this thesis are stated. In the section on research methods, the chosen methods, i.e. SMS and the creation of a web knowledge base are explained in greater detail.

The chapter *Systematic Mapping Study* 5 comprises all steps related to the the SMS. These steps are structured as sections in the thesis, which are dedicated to the definition of the research scope, conduction the search, screening the publications, keywording the abstracts, and data extraction as well as mapping.

In the chapter *Findings* 6, insights from the exploration and analysis of the collected and processed publications data are presented. A diverse range of visualizations is provided in order to depict the publication landscape in the chosen research area from as many different perspectives as possible.

The chapter *Web Knowledge Base* 7 refers to the web knowledge base created for researchers as well as readers to approach their areas of interest within the publications data in a systematic way, and according to the taxonomies used in the systematic mapping study.

The final chapters include the *Implications for Future Research* 9, the *Threats to Validity* 8, and the *Conclusion* 10 as concluding thoughts based on the publications data, the findings, and the output in terms of the knowledge base.

CHAPTER 2

Motivation and Problem Statement

Conceptual modeling sees the underlying reality from a more abstract perspective, which focuses on the necessary features, while leaving out the unnecessary ones [48]. Hence, a conceptual model always remains a partial excerpt or view of the underlying real system which relies on assumptions made relating to the underlying real system [32] [43]. It can also occur on even higher abstraction levels, which is represented by "meta" models, which are basically models of models [32]. To some extent, it also includes semantic parts at this perspective [17]. Key to conceptual modeling as such is the process of determining the right degree of abstraction from the reality, and to determine which features are essential for the model, and which ones can be left out [17] [43]. Next to this, determining the most suitable conceptual model for a specific use is a critical task [43]. There are structural elements that contain for instance "entities, relationship, and constraints", behavioral models that comprise "states, transition, and actions", as well as interaction models that refer to the user interface (UI) and message exchange between constituing elements and actors in the models [17].

Conceptual modeling also comprises the notion of conceptual modeling languages, which can be used for representing the underlying domain in a formal way, thereby providing room for automation (e.g. to generate code fully or partially) [27]. The model can be made explicit by its code and documentation, which constitutes a certain formalization process [48]. It therefore mitigates communication problems, misunderstandings, and can even contribute to "verifying and validating models" in a broader sense [44]. According to Karagiannis et al., CM also involves "describing some aspects of semantics of software applications at a high abstraction level" [27]. More precisely, the entities, relationships, and constraints are used to represent the structure of models, states, actions as well as transitions are used to describe their behavior, and messages are used to illustrate the interactions between the model elements in line with CM [27] [26]. Conceptual models can be applied in a narrow, and domain-specific context, the so called domain-specific language (DSL), but also in a wider and general setting such as Unified Modeling Language (UML), Entity Relationship (ER) modelling, or Object Role Modeling (ORM) [17] [26].

Apart from determining a suitable degree of abstraction, highlighting the goal of CM as a visual support and communication tool among all kinds of stakeholders still represents a challenge in conceptual modeling [17] [44]. Furthermore, transferring the abstract view into formal structures that could be used for inference, while enabling the visual and communication support in the real perspective containing all details is likewise a defying task [17] [32]. Generally speaking, conceptual models come in various forms and shapes, i.e. from non-formal, rather conversational to very formal, mathematically sound ones (e.g. Petri Nets) that have defined rule interlinks [8] [32]. But merely a formal underpinning does not add semantic elements yet, which has to be done by "associating semantics to the language elements", according to Mayr (2021) [32].

Conceptual modeling languages such as UML, Business Process Model and Notation (BPMN), or ER start from a conceptual representation in general or refer to a specific application domain, and its illustration in the form of text or visual elements [32]. Then the constituent concepts are added by the means of "ontological frameworks, or simply using natural language", which are not necessarily related to a "consistent mathematical calculus" [32]. Mayr (2021) added at this point that in practice the visual aspect of communicating conceptual models in the form of diagram among the stakeholders is emphasized most, but the formally specified aspect in terms of ontologies could provide further usage scenarios for the future expansion of CM [32] [44].

In line with an online survey, Fettke (2009) found out that the most frequently used conceptual modeling languages were ER, UML, workflow modeling languages, Event-driven Process Chains (EPC), and ORM, with the former two being used by almost 50% of the respondents frequently in a professional environment among the plethora of conceptual modeling languages available which confirmed again the results collected by Davies (2006) in a previous survey [20] [11]. The most widespread purpose of using conceptual modeling language was identified as "database design and management, software development, improving and documenting business processes, as well as workflow management", according to Fettke (2009), and additionally "enterprise architecture design and planning", according to Davies (2006), but it could be used for a wide range of areas and tasks [20] [11]. As critical "success factors" to use conceptual modeling languages, their "expressiveness, consistency, comprehensibility, and learnability" were mentioned, and later on confirmed by Storey (2017) who extended the focus to a conceptual modeling in context with data-intensive processes [20] [53].

Semantic Web in contrast focuses more on adding meaning to systems and web technologies for input processing automation, meta data generation as well as analysis, and formalized representations of the underlying reality [46]. Berners-Lee (2001), one of the founding personalities of the World-wide Web (WWW), expressed it in a way that the Semantic Web "brings structure to the meaningful content of web pages [...] as an extension to the usual websites“ [4]. Behind that was the intention to enhance the automated processing of websites by extending web pages with meta data and meaning a specific structure that could be read and processed by machines, and ultimately include reasoning within the web via a “semantic markup“ [4].

Such an approach based on inference and rule definitions has proved particularly valuable in an environment where data-intensive applications and therefore the need for automated processing of data semantics are on the rise [4]. So, it somewhat extends the web with logical reasoning that allows to raise and answer complex questions, and infer new knowledge via rules [4] [14]. Some of the basic languages or technologies in line with the Semantic Web are eXtensible Markup Language (XML) which enables tagging of resources with meaning in the form of labels, RDF, and RDFS whose elements are triples that refer to a subject-verb-object combination (such as “*is creator of company*“) each, which defines a relationship between subject and object [4]. Standards like RDF and RDFS rely on data arranged in knowledge graphs, which enable the representation of edges between nodes that adds representation flexibility to the traditional data structures [38]. From this, the notion “linked data“ emerged [61] [3].

Both the subject and the object of a triple are uniquely identified by a URI, so they can be traced back to specific, concrete underlying elements [4]. But at this point, subject and objects would merely have a loose fit between each other as compatibility across different databases and data stores could not be guaranteed [4]. Thus, this fact necessitates the introduction of ontologies, which enable automated “discovery of common meanings“ across data sources, and constitute a “formal representation of the defined relationships between subjects and objects“ [4]. Reusable ontologies create the (not necessarily fully formalized) structure behind and capture the meta data, which glues together the elements of the Semantic Web, by requiring types, and relationship parties amongst other things [4] [23].

Right from the beginning (in the early 2000s), the W3C introduced a standardized approach to the elements of the Semantic Web to treat unstructured data (such as text) and documents, and to prepare the web resources in a way that they can be processed in an automated way more easily [3] [23]. Based on this, the so-called “intelligent agents“, i.e. automated services or programs, pick up, and use the Semantic Web data [23]. This contributed to enhanced efforts to integrate and administrate data according to its meaning as well [23]. The W3C provided Web Ontology Language (OWL) (which emerged from the predecessors OIL and DARPA Agent Markup Language (DAML), and draws upon a description logic basis) and SPARQL Protocol And RDF Query Language (SPARQL) (which is a query language to extract information from knowledge graphs in RDF or RDFS format) as main standards in addition to RDF, RDFS, knowledge graph (KG), Rule Interchange Format (RIF), and linked data [23] [14]. Towards the mid-2010s, a linked open data cloud was developed so that linked data, ontologies, and related queries could be shared and integrated more conveniently, which has been used extensively by projects in geographical information systems (GIS), media and entertainment (such as *DBpedia*), biology, pharmaceuticals, medicine, public services, and academia in general, but did not go as in-depth as ontologies did from a structural point of view [23].

Overall, the Semantic Web has concentrated on integrating data in different shapes and sizes from various data sources, and to organize them more conveniently for further processing and linked data purposes [23]. It has intended a transition from “a web of data to a web of documents“ based on tailored data formats such as RDF, RDFS, Resource Description Framework - eXtensible Markup Language (RDFXML), and N3, and custom query languages such as SPARQL, which aims to make data from various sources more interoperable [38]. The formal approach is reinforced by specified notations like RDF Schema and OWL to include and share defined structures as well as their interrelations using ontologies (with underlying description logic) or less formal vocabularies and taxonomies to provide the so-called linked data [38]. In addition to this, the Semantic Web has become closely intertwined with several other areas, among them sensor networks, cloud computing applications, data-intensive applications, Internet of Things, natural language processing (NLP), and data mining [38] [18]. The different available ontologies, taxonomies, and vocabularies can be matched by the means of machine learning (ML), e.g. rule-based, probabilistic, heuristic, methods [38] [54] [18].

Both **conceptual modeling and Semantic Web** are independent research areas, in which researchers have continued to explore sub-topics. However, the topics also intersect to some extent. For example with regard to ontology creation, they overlap because both use ontologies to “formally represent the conceptualization of a domain“ [46]. Conceptual modeling and semantic web can both be used stand-alone, but can also be combined. Taken together, both conceptual modeling and semantic web help to facilitate processing of data objects and data integration for humans as well as for machines.

Karagiannis et al. (2016) mentioned for instance text annotation to “superimpose a web of knowledge over document collections“ or adding further formal foundations to conceptual models among the main challenges for CM [27]. In context with this, semantic web technologies could provide opportunities. When Sandkuhl et al. (2018) conceived their suggestions for extending conceptual modeling, they mentioned semantic annotation (notably with regard to assistive technologies) and further semantic web topics due to their capability of automated reasoning and inference, next to gamification, knowledge management, architectural thinking, and user-centered innovation [49] [22]. Semantic technologies in combination with conceptual modeling can range from ontology languages that describe conceptual models to rather light-weight semantic annotations, and tools that transform conceptual models to formal ontologies [49].

Conceptual modeling as well as Semantic Web use ontologies, which led to emerging topics like ontology matching, patterns, and analysis, even extended to the meta level [54] [58]. According to Storey (2015), the rise of the Semantic Web contributed to the enhanced use of ontologies in conceptual modeling to add reasoning, and semantics to CM, i.e. it “semantically enriches“ CM [54]. As traditional conceptual models did not comprise “specifications of the semantics of the terminology of the underlying models“, which undermined their consistency, the use of ontologies enabled a more suitable consideration of consistency and semantic aspects [58] [50] [22]. This contributed to new opportunities within conceptual models to apply inference and logical reasoning tasks [58]. Moreover, they both have made advances to accommodate large data quantities in view of big data and related recent trends [54].

For example Zeng (2019) studied in line with a case study how conceptual models from the library, archives, and museum (LAM) domain can be enriched using semantic web technologies [67]. For the researcher, semantic web technologies provided opportunities to "enhance LAM (meta)data's quality, discoverability, and reusability" irrespective of the underlying data's structure [67]. This was achieved by adding "contextualized meanings" with the help of knowledge organization system (KOS) vocabularies and further linked open data resources, as well as of shared ontology infrastructure to ensure the interoperability of heterogeneous content from different sources [67].

Another example for combining both CM and SW is Nogueira's (2018) project to annotate trajectories named FrameSTEP [35]. In this project, location data was used at different abstraction levels. According to Nogueira (2018), conceptual modeling was used in this setting to obtain a higher level view of location data (that came in different formats), and semantic web standards facilitated "interlinking and annotation of trajectories" [35]. For this reason, an existing ontology was adapted to incorporate further contextual meaning, and spatial annotation is done using the "linked open data cloud and OpenStreetMap tags" to extract feature relevant for semantically describing the trajectory's context [35]. Finally, the combination of conceptual modeling with semantic web in this case enabled logical reasoning based on the linked trajectory data [35].

In view of the above, this thesis aims to explore and analyze the publications landscape at the intersection of conceptual modeling and semantic web in terms of research published in recent years by the means of a systematic mapping study, which is an intersection that has not been covered by SMS or Systematic Literature Review (SLR) in this constellation yet. As it was mentioned before, conceptual modeling and semantic web have the potential to complement each other to achieve a benefit over just using either of them exclusively.

CHAPTER 3

Related Work

The chapter 3 comprises previous systematic mapping studies as well as literature reviews that are thematically related to the topics of conceptual modeling and Semantic Web. As no such previous research has been published at the intersection of CM and SW, according to a search in the Scopus publications database, the following query (executed in Scopus) covered research published either on CM or SW. Figure 3.1 shows the query executed on Scopus to retrieve related publications.

(survey OR systematic mapping study OR sms OR mapping study OR systematic mapping) AND (semantic web OR semantic systems OR knowledge graph OR linked data OR linked open data OR ontology OR rdf)

OR

(survey OR systematic mapping study OR sms OR mapping study OR systematic mapping) AND (conceptual model OR modeling language OR modelling language)

Figure 3.1: Scopus query for related work

The query yielded 55 publications across both topics, which were then narrowed down by filtering out unsuitable papers in terms of research field and type, the latter being either a systematic mapping study or systematic literature review. After screening, 11 publications on conceptual modeling and 12 publications on the Semantic Web remained in the relevant subset.

The 11 publications related to **conceptual modeling** are depicted in Table 3.1. They range from the year 2015 to 2022. They are mainly of the research type systematic mapping study, with a minority of two publications being systematic literature reviews.

In 2015, Kosar published a SMS on *Domain-Specific Languages*, which was based on a search query limited to the time span between 2006 and 2012 [29]. It intended to provide

Year	Author	Title
2015	Kosar	Domain-Specific Languages (SMS)
2015	Verdonck	Ontology-driven Conceptual Modeling (SMS, SLR)
2015	Wakil	Model Driven Web Engineering (SMS)
2017	Kolukisa	Ontologies in Software Process Assessm. (SLR)
2017	Wortmann	Modeling for Industry 4.0 (SMS)
2019	Alkharabsheh	Software Design Smell Detection (SMS)
2019	Rodrigues	Legal Ontologies over Time (SMS)
2019	Wortmann	Modeling Languages in Industry 4.0 (SMS)
2020	Iung	Domain-specific Language Development Tools (SMS)
2021	Harley	Data Modeling and NoSQL Databases (SMS)
2022	Zahid	Formal Methods in Requir. Eng. of Industrial CPS (SMS)

Table 3.1: Related publications on CM

a fine-grained understanding of the DSL research field and its evolutionary trends based on a previous work from 2005 [29]. In this paper, the sequential flow from 1153 first query results from Web of Science (WoS) and ACM Digital Library to the final selected 390 publications was documented [29]. In line with the findings, it turned out that the focus in DSL research was usually rather placed on the "development of new techniques / methods rather than investigating the integration of DSL with other software engineering processes or measuring their effectiveness", according to Kosar (2015) [29]. The number of works published did not change either over the years analyzed, meaning that the research field stayed as it is, and "domain analysis, validation, and maintenance" were revealed as areas for further research [29].

Verdonck et al. (2015) rather focused on *Ontology-driven Conceptual Modeling* in their SMS and SLR, which was back then a cutting edge research field [57]. It covered overall 180 publications [57]. Based on the SMS, several "research gaps" were identified, among them the lack of empirical projects, of "model purpose" specification, and of "experimental, observational, and testing evaluation methods" [57]. Verdonck (2015) also recommend to direct more research effort to "how learning, interpretation, and understanding of conceptual representation" [57].

Wakil (2015) explored the topic of *Model Driven Web Engineering* while covering 289 previous publications (from 2000 to 2014), and mainly targeting further development of web platforms [62]. Most publications analyzed contributed a solution or methods, and were dedicated to the sub-topics of "web applicability, notation, or service orientation" [62]. Wakil (2015) identified just as previous works did that future research on validation would be necessary [62].

Kolukisa (2017) tackled the *Use of Ontologies in Software Process Assessment* in their SLR, which analyzes how processes can be evaluated based on a specific process model [55]. The divergence between the actual process and the process model can be used to seize improvement potential for structuring future processes, which can be automated at least partially by ontologies [55]. Thus, the final 14 publications from the 571 original hits (from 2005 to 2016) were intended to determine how much benefit ontologies can bring to the users in such situations [55]. The SLR pointed out that more research on practical applications would be necessary in the future [55].

Wortmann (2017) created a SMS on *Modeling for Industry 4.0* that refers to the use of smart devices and cyber-physical production systems to structure the production process more efficiently [64]. In this SMS accelerating publication activity regarding this topic was discerned among the 222 relevant papers [64]. Most of the publications provide either methods or concepts, however, only very few present experiences and suggestions on metrics for evaluating related tools [64]. UML and to a slightly lower extent DSL turned out as the most frequently used modeling language in this context [64].

The SMS by Alkharabsheh (2019) tackled the topic of *Software Design Smell Detection*, which refer to attributes that negatively impact software quality, based on 395 publications [1]. The SMS systematically depicts with which conceptual modeling technique which design smell can be detected and was detected over time from 2000 to 2017 [1]. The authors state that in the literature analyzed design smells are typically determined as being present or not, but nothing between those two states [1]. So, they call for more research on not so clear cut distinctions between smell or no smell, and for a better "benchmark validation process" to illustrate the positive effect of smell detection on overall quality [1].

Rodrigues (2019) gave an overview on *Legal Ontologies over Time* in their SMS [12]. They stated that the legal ontologies were intertwined with the Semantic Web and used mainly SW standards like RDF and OWL, as well as a high degree of formalization (in the form of description logic) [12]. In addition to this, most legal ontologies covered aimed at "reasoning and problem solving", and to a lesser extent at "domain understanding" for legal cases [12].

Wortmann (2019) extended the earlier SMS from 2017 by also enclosing publications up to 2018, and focused again on the topic of *Modeling Languages in Industry 4.0* [63]. The conclusion remained very similar, saying that UML and DSL prevailed in the field, with increasingly used AutomationML and semantic modeling concepts such as OWL [63].

Iung (2020) published a SMS on *Domain-specific Language Development Tools*, which comprises 59 development tools based on 230 previous research publications [24]. It emerged from the SMS that most tools are non-commercial, and do not provide the capability of transforming DSL models between tools [24]. So, encouraging interoperability between the tools is flagged as an area for future research [24].

The SMS compiled based on 54 publications (from 2008 to 2019) by Harley (2021) refers to *Data Modeling and NoSQL Databases* which frames the change from using mainly UML and ER for conceptual modeling and reflecting relational database structures to rather open NoSQL database models, where for instance JavaScript Object Notation (JSON) and XML are used [37]. The research area indicated steady growth in publications over time [37].

Zahid (2022) provided a SMS on *Semi-formal and Formal Methods in Requirements Engineering of Industrial Cyber-Physical Systems* comprising 93 underlying publications from 2009 to 2020 [65]. According to the authors, publications in that research area concentrate on “formal analysis and verification of safety and timing requirements“ [65]. However, semi-formal methods, privacy-considering methods, and industrial standards are not much represented in the underlying papers, which would suggest potential for further research [65].

Table 3.2 lists the 12 publications related to **Semantic Web** including their publication year and main author. They range from the year 2009 to 2022. They are mainly of the research type systematic mapping study, with a minority of two publications being systematic literature reviews.

Year	**Author**	**Title**
2009	Janev	Maturity and Applicab. Assessm. of SW Techn. (SMS)
2016	Pauwels	Semantic Web Technologies in AEC Industry (SLR)
2016	Zander	SW Techn. for Description of Robotic Components (SMS)
2017	Moussallem	Machine Translation using SW Technologies (SMS)
2018	De Souza Neto	Semantic Web and Human Computation (SMS)
2018	Sabou	Semantic Web Services Testing (SMS)
2019	Alloghani	The XML and Semantic Web (SMS)
2019	Gacitua	The XML and Semantic Web (SMS)
2020	Dadkhah	Semantic Web Enabled Software Testing (SLR)
2020	Drury	Semantic Web Technology for Agriculture (SMS)
2021	Enriquez-Reyes	Using SW Techn. in Dev. of Data Warehouses (SMS)
2022	Senthil	SW Techn. in Healthcare (SMS)

Table 3.2: Related publications on SW

The SMS by Janev (2009) deals with the topic *Maturity and Applicability Assessment of Semantic Web Technologies*, which includes technologies and tools used in the SW field [25]. As benefits, the authors determined “data reuse and sharing, improved search, open or incremental modeling, decreased implementation time, and customization to individual cases“, and identified that SW is typically supported by conceptual modeling (e.g. using UML) [25]. Still, ontologies have not yet been developed in a systematic way, which should be reinforced in the future [25].

Pauwels (2016) published a SLR on *Semantic Web Technologies in the Architecture, Engineering, and Construction (AEC) Industry*, which are increasingly used in addition to tradition building information modeling technologies [39]. As the main advantages of SW technologies in this field, interoperability with different software tools and seamless integration with other data formats are pointed out [39]. The logical basis in terms of inference capabilities is also seen as a benefit that has not been provided by other systems till then, which could significantly contribute to the evolution of information modeling and systems in the AEC sector. but still requires tailoring towards human use together with other systems [39].

Zander (2016) conducted a SMS on the *Usage of Semantic Technologies for the Description of Robotic Components and Capabilities*, which focused on the "application of semantic technologies and ontology-based knowledge representation frameworks" in a cyber-physical systems environment [66]. Ontologies in that area serve mainly to "express metadata models of hardware and software components" and contribute to mode-driven engineering [66]. According to Zander (2016), the research area was a growing one, from which the recent focus on logical reasoning stood out, which is not available in classical component modeling (e.g. with UML) [66].

The SMS (comprising 21 publications) by Moussallem (2017) referred to the topic of *Machine Translation using Semantic Web Technologies* [33]. By using semantic technologies in this context, translation across different languages can be facilitated thanks to lower ambiguity as well as a systematic logical approach, and quality can therefore be enhanced [33]. However, quality metrics still need to incorporate ways to measure semantics.

The SMS by De Souza Neto (2018) deals with *Semantic Web Services Testing* and extended previous work with publications data from 2011 to 2017 comprising 43 publications [13]. It identified several trends in the research area such as the fact that the majority of publications cover uni or integration test case generation, the large prevalence of Petri Nets being used for model transformation, and OWL as a SW standard [13]. Moreover, the SW can essentially contribute to automate processes in web service testing[13].

Sabou (2018) published a SMS on *Semantic Web and Human Computation: The Status of an Emerging Field*, which provided insights into an intersection of two topics [45]. Based on publications from 2008 to 2018, it has matured as a research area as papers moved from conference proceedings to journal articles [45]. The most popular topics within the research area are "ontology engineering and knowledge validation" [45]. More research would be necessary regarding "reusable tools, semantic annotation, and user interfaces" [45].

Alloghani (2019) conducted a SMS on *The XML and Semantic Web*, which focuses on the "difference between SW and XML data models and queries", and is targeted at encouraging interoperability between those two model areas based on 50 publications (from 2010 to 2018) [2]. At this point, it turned out that Semantic Web technologies could entail a higher level of interoperability and integration to data models than only XML offers [2].

In their SMS, Gacitua (2019) analyzed the topic of *Using Semantic Web Technologies in the Development of Data Warehouses* [21]. This study identified that due to a lack of technological options, SW is not adopted as much in business as it could, and can therefore not realize its full extent of benefits [21]. Furthermore, a large gap between theory and application in practice (in terms of project size and technology scope) persists [21].

Dadkhah (2020) published a SLR on *Semantic Web Enabled Software Testing*, which comprises 52 initial, and 10 thoroughly analyzed papers [10]. From this SLR emerged that both testing applications in research and practice can be improved using Semantic Web technologies.

The SMS published by Drury (2019) comprised 25 papers and dealt with *Semantic Web Technology for Agriculture*, thus for domain-specific applications [15]. Several institutions in the agricultural domain established semantic resources, but their adoption has remained quite limited in practice [15]. As the agricultural sector creates large quantities of (in many cases unstructured) raw data from sensors and other devices, this constitutes a viable entry point for semantic technologies to make better use of the data and pre-process it for analysis as "the usefulness comes from context and meaning", according to Drury (2019) [15]. Semantic web technologies can therefore help to make data formats compatible, services interoperable, and share or match meaning thanks to ontologies [15]. Overall, the most institutions created individualized ontologies for their purpose, and only very few used domain-spanning ontologies [15]. These insights and the fact that only little research was available on the topic, called for more research into industry-spanning ontologies in the agricultural domain [15].

Enriquez-Reyes (2021) elaborated on the topic of *Open Data Studies* to identify technological trends in that research area by the means of a SMS covering 839 publications from 2006 to 2019 [16]. It turned out that interest in the research area had grown fast up to the start of the 2010s, but then reached a mature state towards the late 2010s [16]. The SMS led to the findings that semantic technologies can contribute to the reuse and standardization of linked open data [16].

Senthil's (2022) SMS on *Utilizing Semantic Web Technologies in Healthcare, Virtual Communities, and Ontology-based Information Processing Systems* concentrated notably on ontology creation and reuse as well as on semantic data retrieval in the named fields [30]. Senthil (2022) noted that the "role of semantic web is becoming pervasive" in those areas, and that publication activity has risen sharply over the last couple of years [30]. SW technologies appeared to bring integration and interoperability capabilities to software projects, and freely accessible ontologies such as *DBpedia* or *schema.org* are frequently used as role models or compatible ontologies to integrate one's own ontology with [30].

As it could be seen from above, previous works exist on either conceptual modeling or Semantic Web, but the intersection of the two topics has not been covered by a systematic mapping study yet. Thus, this thesis provides insights into an area that has not be tackled yet. The review of related literature also revealed that many studies dedicated to specific niche topics or domains. Some of them touched upon sub-topics of both CM and SW, but still provided no systematic overview at a general level. This thesis therefore aims to elaborate on the publication landscape covering the intersection of conceptual modeling and Semantic Web at a general level to close the identified research gap.

CHAPTER 4

Research Questions and Methods

4.1 Research Questions

This systematic mapping study aims to explore the research landscape at the intersection of conceptual modeling and the Semantic Web from various angles. For this reason, the publications data is classified according to several taxonomies referring to conceptual modeling, Semantic Web, or the combination of both. Based on this, seven research questions (RQ) were defined.

- **RQ1:** *How has the research area at the intersection of conceptual modeling and Semantic Web evolved over time in general, and with regard to publication, research, contribution type, as well as modeling purpose?*

  The question is motivated by the search for a trend that might occur in the general evolution or in specific features such as publication type, research type, contribution type, or modeling purpose. It aims to offer a more detailed and multi-faceted picture of the publications in the research area.

- **RQ2:** *Which ones are the main contributing institutions, in what publication media did they publish their research, and in which countries were those institutions located?*

  This research question intends to give a geographical overview on where hubs covering this research area are located, and more precisely which organizations contributed most. Furthermore, the publication channels in terms of journal, book or conference media, where the research is published, are analyzed.

- **RQ3:** *Who are the main contributing researchers and research communities in the field, what topics are they focusing on, and how do these research groups interact?*

This question was raised with the aim of determining the main research communities at the intersection of CM and SW as well as the topics that they concentrate on. In addition to this, the relationships between the research communities, and the countries where the contributing institutions are located, are analyzed in greater detail.

- **RQ4:** *Are the contributions in the CM-SW field attributed to foundational research or rather to specific industries / domains, and what kind of conceptual modeling languages are used?*

  RQ4 is motivated by the fact that publications in the CM-SW field belong either to foundational research or to domain- / industry-specific research. Thus, in line with the elaboration of this research question, this characteristic is illustrated. Moreover, most publications in this research area refer to at least one conceptual modeling language, which is subject to analysis at this point.

- **RQ5:** *In what kinds of semantic technology segments and W3C main area did the contributions occur, what SW standard(s) did they use*?

  This research question intends to obtain closer insights into the Semantic Web part and how characteristics such as semantic technology segments, W3C main areas, and Semantic Web standards are related to the publications at the intersection of CM and SW.

- **RQ6:** *What value added can conceptual modeling in combination with Semantic Web achieve?*

  RQ6 aims to find out how conceptual modeling in combination with Semantic Web can provide added value and benefits to the users. This question was motivated by the fact that conceptual modeling and Semantic Web each offer specific advantages, but their combined benefit would be an interesting research addition.

- **RQ7:** *What clusters does the combined analysis along two taxonomies reveal?*

  RQ7 is based on the thought of combining several taxonomies to obtain more fine-grained mapping results. In doing so, the combined analysis along taxonomies can present new findings and clusters.

4.2 Methods

4.2.1 Systematic Mapping Study

The research questions that were outlined above will be answered by the means of a systematic mapping study (SMS) based on the methodological works of Petersen (2008) [42] and Kitchenham (2011) as a foundation [28]. According to Kitchenham a systematic mapping study is methodologically somewhat related to a systematic literature review (SLR), but emphasizes rather the goal of achieving a “wide overview of the research area“ under concern for scientists with regard to publication activity, evolution over time, and content, and involves a classification scheme [28]. The SMS covers both qualitative as well as quantitative techniques to depict the research area, and intends to classify the publications in the research area under concern according to taxonomies [19]. The research questions are therefore formulated in a way that research trends, evolution, and publication activity can be observed systematically based on the used taxonomies.

At this point, it appears as an appropriate solution approach to explore the thesis topic, which dedicates to examine the research published at the intersection of conceptual modeling and Semantic Web. This is notably due to the fact that an SMS provides the opportunity to get a multi-faceted understanding of the current state of the research area along the chosen dimensions and categories, and to detect content gaps that might constitute viable ideas for upcoming research projects [28] [42]. Overall, the SMS was chosen as research method for this thesis as it seeks to systematically present the chosen research area, classify publications, thematically analyze selected publications, and facilitate the understanding of research trends and topics for both new and experienced researchers.

In relation to the steps of the systematic mapping study, this thesis uses the widely used SMS framework elaborated by Petersen (2008), which comprises the following **phases** [42][1] that are described in greater detail in chapter 5:

- **Define research scope**
  The research scope is influenced notably by the research questions, which have been formulated in section 4.1 *Research Questions*. They seek to gather information on research and contribution types of the publications at the intersection of conceptual modeling and Semantic Web, to identify the modeling purpose and languages used in the corresponding conceptual models, and to outline the major research communities in the respective research field. In addition to this, the thesis explores whether the publications related to a specific industry or domain, or whether they represent foundational research. The semantic technology segments where the contributions occur and what modeling purpose they served is investigated. Finally, the thesis evaluates what benefits can be achieved by the means of combining conceptual modeling with Semantic Web.

- **Conduct search**
  As the objective is to investigate the intersection of conceptual modeling and Semantic Web, the search query contains two parts, i.e. one related to conceptual modeling, and the other related to Semantic Web which are subsequently combined using the logical operator “and“ in order to get the intersection. The queries for the two areas draw partially upon knowledge and examples from previous systematic mapping studies and further literature (e.g. [45], [61]). Several queries are tried in order to grasp the field best possible, and finally select the most suitable one. The query has to be refined as necessary. For some of the query terms, synonym ways

[1]Note: Literature source refers to all phases mentioned below.

of writing are used so that papers using any variant of them are included in the search result. The queries are formulated in English, as this SMS limits itself to publications written in English.
The query is then executed in literature search engines (considering title and abstract) such as Scopus[2], IEEE Xplore[3], ACM Digital Library[4], and Web of Science[5]. All search results are exported.

- **Screen papers**
  In the screening phase, the criteria with regard to which search results to include (i.e. deemed relevant) or exclude (i.e. deemed non-relevant) for the subsequent phases, are defined. For example papers from non-computer science areas are excluded, and papers below or above a specified length are excluded. For instance papers that are peer-reviewed (e.g. journal articles, books, conference proceedings), and are written in English are included.
  The citation files (in BibTeX format) of the search results are downloaded using the Application Programming Interface (API) for Scopus, and the online interface for the remaining search engines. The BibTeX files are converted to CSV format, and the duplicates are removed using Python scripts. For each filtering step, the number of papers involved is tracked.
  As follows, the abstracts of the remaining publications are downloaded, and analyzed with regard to their relevance for this SMS. For the documents considered relevant, the full text version is downloaded, and is prepared for reading. At this stage, the publications are ready for mapping to the elaborated classification scheme.

- **Keyword abstracts**
  The abstracts are analyzed and keywords, which appear to characterize the publications' main content and contribution, are assigned in order to formulate the classification scheme. In line with classification, a taxonomy is created in order to assign the publications accordingly. The taxonomies comprise several components, namely the W3C main areas of Semantic Web [61], the Semantic Web activity areas [59], the semantic technology segments [25], the Semantic Web standards [60], research types, contribution types, modeling purposes for conceptual modeling, and value added by combining CM and SW. The output of this phase is the classification scheme, i.e. the taxonomies [42].

- **Extract and map data**
  The remaining relevant publications are mapped to the classification scheme along the dimensions stated in the previous step. The mapping is subject to a feedback round, and review to capture possibly occurring gaps or errors. Based on the mapping results, a content analysis is carried out as necessary, and a series of plots,

[2]https://www.scopus.com/search/form.uri?display=advanced (last accessed on 24 November 2022)
[3]https://ieeexplore.ieee.org/search/advanced (last accessed on 24 November 2022)
[4]https://dl.acm.org/search/advanced (last accessed on 24 November 2022)
[5]https://www.webofscience.com/wos/woscc/advanced-search (last accessed on 24 November 2022)

tables, and figures are created in order to depict the results in a visually appealing and systematic way (using Python scripts, R scripts, and VOSviewer[6]), so that the insights can be conveyed well. The output of this phase is the systematic mapping of research publications according to the taxonomies [42].

4.2.2 Knowledge Base

Complementary to the systematic mapping, a web knowledge base containing information on the publications relevant for this project is created in order to enable researchers to retrieve an excerpt and related meta data of the results of the SMS that they are interested in, according to their specified criteria. The search can be done by the elements of the taxonomies and by year. The title, publication year, authors, and the assigned taxonomy elements will be shown, and the abstract can be displayed on demand. The name of the publication will be displayed in a way that a hyperlink is embedded in it to enable the users to directly go to the full text version of the desired publication. The results page will show the list of retrieved publications according to the entered search criteria or keywords.

[6]https://www.vosviewer.com/ (last accessed on 24 November 2022)

CHAPTER 5

Systematic Mapping Study

5.1 Definition of Research Scope

The first phase of the systematic mapping study is the definition of the research scope, which refers to the outline of research questions. As according to Petersen (2008), a SMS intends to "provide an overview of the research area, and identify the quantity and type of research", the development of the research field over time constitutes a first main research objective [42]. Subsequently, further characteristics such as the publication media, or different splits or combinations of the classification schemes can be used to obtain more fine-grained insights into the research area, in this case the publications at the intersection of conceptual modeling and Semantic Web [42].

Therefore, the research questions and their respective motivation mentioned above in the chapter *Research Questions* delineate the research scope. RQ1 refers, just like outlined above, to the general evolution of the research area over time and more specifically with regard to the publication, research, contribution type, as well as modeling purpose. RQ2 points towards an analysis of the main contributing institutions, publication media, and countries of contributors. In line with RQ3, the research communities are of interest for more detailed analysis, and the links between researchers as well as research communities and their topic focus are subject to further inspection. Subsequently, RQ4 takes a closer look at whether the publications constitute foundational research or can be attributed to specific industries or domains, and what kind of CM languages are used. RQ5 considers the Semantic Web component by analyzing the spread of the publications across semantic technology segments, W3C main areas, and SW standards. RQ6 intends to seize what value added can be achieved by combining conceptual modeling and Semantic Web. RQ7 finally dedicates to the combined analysis along several taxonomies so that multi-faceted insights emerge.

5.2 Conducting the Search

According to Petersen (2008), the search conduction phase follows after the research scope, i.e. the research questions, have been defined [42]. In the first place, several query options have been explored so that one final, best-fitting search query can be chosen. In this thesis, the search query comprises two parts, namely the one covering the area of *conceptual modeling*, and the other referring to the area of *Semantic Web*, which were joined by the operator *and* so that the intersection of the topics resulted.

The query parts were not randomly tried, but relied on knowledge and content from prior systematic mapping studies and related literature, notably from Sabou (2018) [45] for the Semantic Web part who published a SMS on *Semantic Web and Human Computation: The status of an emerging field*, Bork (2022) [6] for the conceptual modeling part who published a SMS on *Conceptual Modeling and Artificial Intelligence: A Systematic Mapping Study*, and W3C [61]. Further key words for the search query development stem from the lecture materials of the courses *VU Introduction to Semantic Systems* and *Semi-Automatic Information and Knowledge Systems* by Sabou (2020) from the Vienna University of Technology (TU Wien) [46].

The following figures show the process from search query 1 to search query 3 (in Scopus query notation) in which the query in the selected publications databases ACM Digital Library[1], IEEE Xplore[2], Scopus[3], and Web of Science[4] was adapted in order to finally select the most suitable for the purpose of this thesis. The query key words comprised several ways of writing, and different orthographic forms so that publications which contained very closely related key words, were also included in the query results. The queries were written in English as the SMS only considers publications in English.

The conceptual modeling and the Semantic Web query parts are both highlighted in color. The search was executed in the title and abstract of publications recorded in the chosen publications databases.

```
TITLE-ABS-KEY ( ( ( {conceptual modeling} OR {conceptual modelling} OR {metamodel} OR {meta-model} OR {metamodels} OR {meta-models} OR {domain specific language} OR {domain-specific language} OR {domain specific languages} OR {domain-specific languages} OR {modeling formalism} OR {modelling formalism} OR {modelingformalisms} OR {modelling formalisms} OR {modeling tool} OR {modelling tool} OR {modeling tools} OR {modelling tools} OR {modeling language} OR {modelling language} OR {modeling languages} OR {modelling languages} OR {modeling method} OR {modellingmethod} OR {modeling methods} OR {modelling methods} OR {modeldriven} OR {model-driven} OR {mde} ) AND ( {knowledge graph} OR{knowledge graphs} OR {linked data} OR {linked-data} OR {semanticweb} OR {ontolog} OR {RDF} OR {OWL} OR {SPARQL} OR {SHACL} ) ) ) AND ( LIMIT-TO ( SUBJAREA , "COMP" ) )
```

Figure 5.1: Search query 1 (Scopus notation)

[1]https://dl.acm.org/search/advanced (last accessed on 24 November 2022)
[2]https://ieeexplore.ieee.org/search/advanced (last accessed on 24 November 2022)
[3]https://www.scopus.com/search/form.uri?display=advanced (last accessed on 24 November 2022)
[4]https://www.webofscience.com/wos/woscc/advanced-search (last accessed on 24 November 2022)

Figure 5.1 shows the first search query, and Figure 5.2 the second, extended search query. Figure 5.3 depicts the third search query that was refined based on the second one, and was selected as a final search query for this systematic mapping study.

TITLE-ABS-KEY ((({conceptual modeling} OR {conceptual modelling} OR {metamodel} OR {meta-model} OR {metamodels} OR {meta-models} OR {domain specific language} OR {domain-specific language} OR {domain specific languages} OR {domain-specific languages} OR {modeling formalism} OR {modelling formalism} OR {modelingformalisms} OR {modelling formalisms} OR {modeling tool} OR {modelling tool} OR {modeling tools} OR {modelling tools} OR {modeling language} OR {modelling language} OR {modeling languages} OR {modelling languages} OR {modeling method} OR {modellingmethod} OR {modeling methods} OR {modelling methods} OR {modeldriven} OR {model-driven} OR {mde}) AND ({knowledge graph} OR{knowledge graphs} OR {linked data} OR {linked-data} OR {semanticweb} OR {ontolog} OR {RDF} OR {OWL} OR {SPARQL} OR {SHACL} OR {semantic systems} OR {semantic system} OR {semantic technologies} OR {semantic technology} OR {RDFS} OR {protege}))) AND (LIMIT-TO (SUBJAREA , "COMP"))

Figure 5.2: Search query 2 (Scopus notation)

TITLE-ABS-KEY ((({conceptual modeling} OR {conceptual modelling} OR {metamodel} OR {meta-model} OR {metamodels} OR {meta-models} OR {domain specific language} OR {domain-specific language} OR {domain specific languages} OR {domain-specific languages} OR {modeling formalism} OR {modelling formalism} OR {modelingformalisms} OR {modelling formalisms} OR {modeling tool} OR {modelling tool} OR {modeling tools} OR {modelling tools} OR {modeling language} OR {modelling language} OR {modeling languages} OR {modelling languages} OR {modeling method} OR {modellingmethod} OR {modeling methods} OR {modelling methods} OR {modeldriven} OR {model-driven} OR {mde}) AND ({knowledge graph} OR{knowledge graphs} OR {linked data} OR {linked-data} OR {semanticweb} OR {ontolog} OR {RDF} OR {OWL} OR {SPARQL} OR {SHACL} OR {semantic systems} OR {semantic system} OR {semantic technologies} OR {semantic technology} OR {RDFS} OR {protege} OR {SKOS} OR {simple knowledge organisation system} OR {JSON-LD} OR{rule interchange format} OR {semantic modeling} OR {semantic modelling} OR{linked open data} OR {vocabularies}))) AND (LIMIT-TO (SUBJAREA , "COMP"))

Figure 5.3: Search query 3 (Scopus notation)

Table 5.1 shows the results yielded from the different search queries across the four publication databases. In the case of ACM Digital Library, the search queries generated around 240 to 260 hits, in IEEE Xplore around 720 to 760 hits, in Scopus around 1700 to 2100 hits, and in Web of Science around 1900 to 2000 hits (see 5.1).

Publication database	**Search query**	**Nr. of hits**
ACM Digital Library	Query 1	239
ACM Digital Library	Query 2	242
ACM Digital Library	Query 3	256
IEEE Xplore	Query 1	722
IEEE Xplore	Query 2	726
IEEE Xplore	Query 3	760
Scopus	Query 1	1755
Scopus	Query 2	1855
Scopus	Query 3	2092
Web of Science	Query 1	1888
Web of Science	Query 2	1906
Web of Science	Query 3	1999

Table 5.1: Query results

5.3 Screening of Publications

In line with the screening phase, various criteria to distinguish between relevant (i.e. inclusion criteria (IC)), and non-relevant publications (i.e. exclusion criteria (EC)) were defined. The following **inclusion criteria** were chosen in this thesis:

- IC1: Publication is written in English
- IC2: Publication is in the area of computer science
- IC3: Publication is peer-reviewed (i.e. journal article, book, conference proceeding)
- IC4: Publication length >= 4 and <150 pages
- IC5: Relevant abstract

Publications were excluded according to the following **exclusion criteria** for this SMS:

- EC1: Duplicates based on DOI
- EC2: Duplicates based on title
- EC3: Published before 2005
- EC4: Publication length <4 or >150 pages
- EC5: Non-relevant abstract
- EC6: Duplicates based on manual check

The exclusion and inclusion criteria related to the language (see IC1), area (see IC2) and peer-reviewed publication type (see IC3) were already applied in the query in the respective publication databases using search query 3 (see 5.3). Based on the exported data fields, the further exclusion criteria were applied, which is illustrated in Figure 5.4. The number of publications for further review was reduced from initially 5107 to 484. Starting from 5107 publications, 4349 were left after automated removal of duplicated based on Digital Object Identifier (DOI) (see EC1). In the subsequent step, the number of publications was narrowed down to 4145 using an automated check for duplicates based on publication title (see EC2). Then all pieces of research that were published before 2005 were removed, which lowered the number of publications to 3865 (see EC3). All publications with fewer than 4 pages or more than 150 pages were removed, which left 3090 publications in the list (see EC4 and IC4). Then the abstracts were reviewed and labelled either as relevant (see IC5) or non-relevant (see EC5) for the topic of the SMS, which narrowed the list of publications under concern down to 492 publications. Based on a final manual duplicate check (see EC6), the number of publications was again reduced to 484 publications which were selected for further analysis.

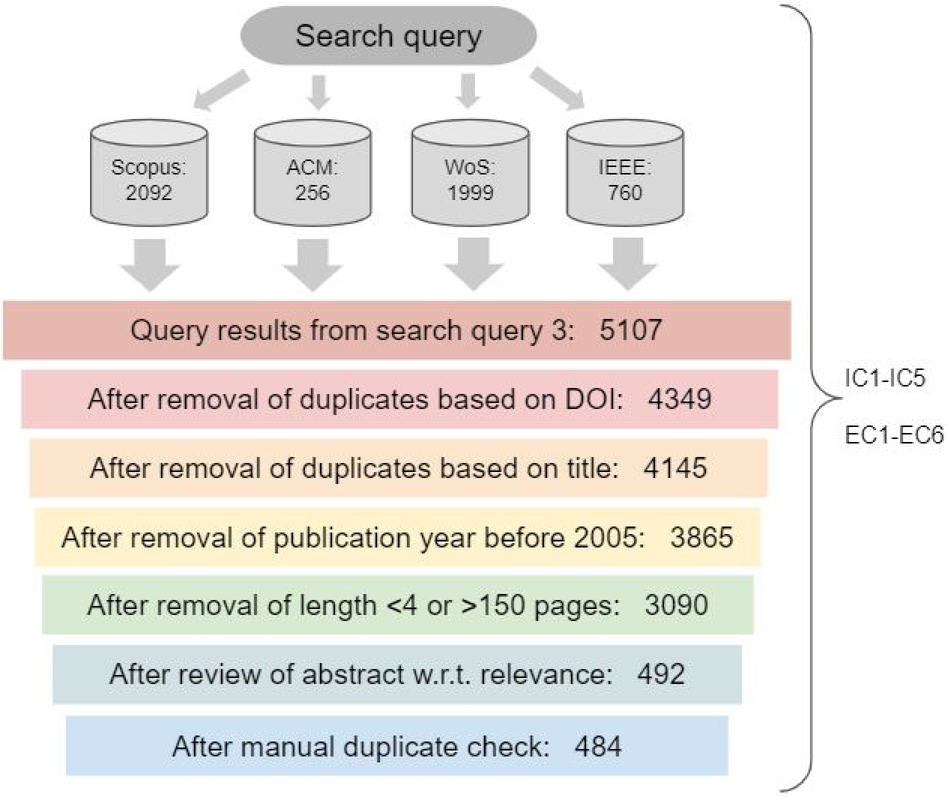

Figure 5.4: Publication search and screening process

The reduced list of search results was exported in the form of BibTeX citation files using the Scopus API as well as the online UI for the remaining publications that were not available via Scopus in an automated way. The information on title, abstract, DOI, publication year amongst others were transformed into CSV format, and rendered using Python scripts so that a standardized format emerged. For the publications, whose abstracts were marked as relevant, the full text version was downloaded, and prepared for further review and for the development of the classification schemes. For further reference, the final list of publications included in the SMS is enclosed in the Appendix 10.

5.4 Keywording Abstracts

In this phase of the SMS, the abstracts are reviewed with regard to keywords, which appear to characterize the publications' main content and contribution [42]. In doing so, the relevant classification schemes, i.e. the taxonomies, considering the filtered list of publications are generated [42]. Zero, one, or several categories might be assigned to the publications depending on the respective taxonomy. In this thesis, the taxonomies were chosen in accordance with the needs to answer the research questions, and are the W3C main areas of Semantic Web [61], the Semantic Web activity areas [59], the semantic technology segments [25], the Semantic Web standards [60], research types, contribution types, modeling purposes for conceptual modeling, and value added by combining CM and SW. The final result of this SMS phase are the taxonomies, i.e. the classification schemes [42]. In the subsequent part, the taxonomies are outlined.

5.4.1 W3C Main Areas of Semantic Web Taxonomy

The following taxonomy refers to the W3C Main Areas of Semantic Web, and comprise the categories *Linked Data*, *Queries*, *Vocabularies*, and *Inference* which are described in as follows [61] [60]:

- **Linked Data**[5]:
  "Collection of interrelated datasets" which is available in a standardized format that "provides an environment where applications can query the data, draw inferences using vocabularies", where "relationships among data" are defined, and which is "fit for use" by semantic tools [61] [60].

- **Vocabularies**[6]:
  "Vocabularies define the concepts and relationships (i.e. terms) used to describe and represent an area of concern to classify the terms that can be used in an application, characterize possible relationships, and define possible constraints on using terms". Here, vocabularies also comprise ontologies, which are more complex and formal term collections. Vocabularies in the narrower sense do not require such strict formalism [61] [60].

- **Queries**[7]: "Technologies and protocols that can programmatically retrieve information from linked data" [61] [60].

[5] https://www.w3.org/standards/semanticweb/data (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[6] https://www.w3.org/standards/semanticweb/ontology (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[7] https://www.w3.org/standards/semanticweb/query (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

- **Inference**[8] Inference refers to the “automatic procedures used to generate new relationships based on the data and additional information from vocabularies (e.g. rule sets)“. Inference means “reasoning to discover new relationships“ [61] [60].

5.4.2 W3C Activity Areas Taxonomy

The W3C Activity Areas taxonomy refers to either foundational piece of work in the field of Semantic Web, or the respective activity domains into which use cases are for instance classified [59]. The following categories form part of the activity areas[9]:

- **Foundational**: General foundational research in the context of Semantic Web technologies, which is not specifically tailored to an application domain.
- **Application lifecycle management**
- **Arts**
- **Manufacturing**
- **Media**
- **Cultural**
- **Education**
- **Government**
- **Energy**
- **Financial**
- **Tourism**
- **Geographical Information System**
- **Healthcare**
- **IT**
- **Legal**
- **Life sciences**
- **Oil and gas**

[8]https://www.w3.org/standards/semanticweb/inference (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[9]https://www.w3.org/2001/sw/sweo/public/UseCases/ (last accessed on 24 November 2022) (Note: Source refers to the whole list of bullet points.)

- **Service management**
- **Telecommunications**
- **Utilities**

5.4.3 Semantic Technology Segments Taxonomy

The semantic technology segments taxonomy is composed of the elements *semantic data management and integration*, *semantic modeling and development*, *learning and reasoning*, *semantic collaboration incl. portal technologies*, *semantic annotation*, and *semantic search and retrieval*, which are described in the following paragraphs [60] [59] [25][10]:

- **Semantic data management and integration**: “Ontology-driven information systems and server platforms that enable RDF triple storage, semantic data / service integration and management, semantic interoperability based on W3C standards (XML, RDF, OWL, service oriented architecture (SOA), Web Services Description Language (WSDL), Business Process Execution Language for Web Services (BPEL4WS))” [25]. Janev’s (2009) publication on the ”maturity and applicability assessment of Semantic Web technologies” was used as a foundation for this taxonomy [25].
- **Semantic modeling and development**: “Tools that enable design and development of ontologies, RDF or OWL knowledge stores, and tools for semantic services applications development“ [25].
- **Semantic collaboration incl. portal technologies**: “Portals based on semantic standards (RDF, OWL), semantic wiki technology; solutions that support social networking, data aggregation, dynamic publishing of contents and media“ [25].
- **Learning and reasoning**: “(OWL) reasoners, ontology learning tools, rule engines“ [25].
- **Semantic annotation**: “Technologies that support automatic semantic annotation, information extraction, text mining, other language processing tasks” [25].
- **Semantic search and retrieval**: “Semantic data access and search tools based on W3C standard query languages (XML Query Language (XQUERY), SPARQL), semantic search engines based on NLP, linguistic analysis, text mining, and technologies incl. content classification, categorization, and clustering; fact and entity extraction, taxonomy creation, and management (tagging engines); knowledge presentation” [25].

[10]Note: Sources refer to the whole list of bullet points.

5.4.4 Semantic Web Standards Taxonomy

The Semantic Web standards taxonomy includes a number of W3C standards that are explained as follows [61] [60].

- **RDF**: It is a "standard model for data interchange and linking on the web" and provides schemas to enable easier data integration and is represented in graph notation [11].
- **OWL**: OWL "is a Semantic Web language" used for representation in the form of knowledge graphs, and logical knowledge including the relationships between its parts[12].
- **SPARQL**: It is a query language used to extract relationship data and graph data from knowledge graphs, and semantic data formats[13].
- **RDFa**: RDFa means "RDF in Attributes" and constitutes a "specification for attributes to express structured data in HTML5, XHTML, and any XML application", and it is able to work with semantic data formats such as RDF triples[14].
- **JavaScript Object Notation for Linked Data (JSON-LD)**: This standard refers to JSON format which is tailored to the use in the context of linked data[15].
- **Simple Knowledge Organization System (SKOS)**: It means Simple Knowledge Organization System and "is a common data model for sharing and linking knowledge organization systems (e.g. taxonomies, classification schemes, thesauri)" online[16].
- **RDFS**: RDFS is, just like RDF, a linked data format, refers to the schema, and "represents simple RDF vocabularies online" which constitutes the foundation for more complex ontologies[17].
- **Gleaning Resource Descriptions from Dialects of Languages (GRDDL)**: GRDDL "is a technique for obtaining RDF data from XML documents and in

[11] https://www.w3.org/2001/sw/wiki/RDF (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[12] https://www.w3.org/2001/sw/wiki/OWL (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[13] https://www.w3.org/2001/sw/wiki/SPARQL (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[14] https://www.w3.org/2001/sw/wiki/RDFa (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[15] https://www.w3.org/2001/sw/wiki/JSON-LD (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[16] https://www.w3.org/2001/sw/wiki/SKOS (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[17] https://www.w3.org/2001/sw/wiki/RDFS (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

particular Extensible Hypertext Markup Language (XHTML) pages“, and is open to integrate further algorithms and procedures necessary to handle semantic data[18].

- **Protocol for Web Description Resources (POWDER)**: POWDER offers “a mechanism to describe and discover Web resources and provide a succinct way to define any number of predicates for those resource“ to more easily integrate data into big linked data systems (usually based on RDF)[19].

- **Provenance (PROV)**: PROV is a “provenance specification“ which enables the “exchange of provenance information“ in linked data format[20].

- **RIF**: This standard refers to a rule interchange format, which helps to “interchange rules between different logical-based systems“[21].

- **Semantic Annotations for WSDL and XML Schema (SAWSDL)**: SAWSDL “defines extension attributes for WSDL and XML schema definition language that allows description of additional semantics of WSDL components, which specifies how semantic annotation is accomplished using references to semantic models“[22].

- **Relational Databases to RDF (RDB2RDF)**: RDB2RDF is a “collection of two Recommendations to map the content of relational databases to RDF“, which uses “direct mapping and RDB to RDF Mapping Language (R2RML)“ as mapping languages that transform linked data from one to another format[23].

- **SHapes And Constraints Language (SHACL)**: SHACL is a “standard language for describing shape of RDF data which is used for validating conditions in a linked data and graph data setting (e.g. triples) by referring to numeric ranges, string patterns, values, and the like“[24].

5.4.5 Research Type Taxonomy

The publications can be classified by research type as *Vision*, *Solution*, *Evaluation*, or *Experience* [63] [41] [40] [42]. The precise meaning is explained as follows:

[18] https://www.w3.org/2001/sw/wiki/GRDDL (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[19] https://www.w3.org/2001/sw/wiki/POWDER (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[20] https://www.w3.org/2001/sw/wiki/PROV (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[21] https://www.w3.org/2001/sw/wiki/RIF (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[22] https://www.w3.org/2001/sw/wiki/SAWSDL (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[23] https://www.w3.org/2001/sw/wiki/RDB2RDF (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

[24] https://www.w3.org/2001/sw/wiki/SHACL (last accessed on 24 November 2022) (Note: Source refers to the whole paragraph.)

- **Experience**: “Explain on what and how something has been done in practice, referring to personal experience of author(s)” [42].
- **Evaluation**: “Observation of how a technique is implemented to solve a research problem (solution implementation and measure consequences in terms of benefits and drawbacks)” [41] [42].
- **Solution**: New solution or extension of existing solution to a problem, whose applicability is shown by an example or a solid argumentation [40] [42].
- **Vision**: “Non-disruptive research agenda setting papers” [63].

5.4.6 Contribution Type Taxonomy

The contribution type taxonomy comprises the categories *Discussions*, *Concepts*, *Methods*, *Algorithms*, and *Tools*, and are defined in the following list [63] [42] [40]:

- **Discussions**: “Investigations without constructive contributions (e.g. reviews, comments, opinions)” [63].
- **Concepts**: “Suggestions of ways of thinking (e.g. meta-models, frameworks, taxonomies) that are constructed from a set of statements, assertions, or other concepts” (5)(7) (incl. mathematical theories) [40] [42].
- **Methods**: “Suggestions of new ways of doing things (e.g. applying existing models) by means of actionable instructions that are conceptual (not algorithmic)” [40] [42].
- **Algorithms**: “Suggestions of new automatic ways of computing (e.g. model transformation) or measuring things (e.g. metrics) by means of formal logical instructions” [40].
- **Tools**: “Presenting novel software tools (e.g. modeling tools)” [42] [63].

5.4.7 Modeling Purpose Taxonomy

The modeling purpose taxonomy comprises the elements *Representation*, *Analysis*, *(Re-)Design*, and *Code Generation* [27] [6] [34] [7] [36] [9] [56] [52][25]:

- **Representation**: “Creation of abstract representations of the system under study (descriptive modeling)”
- **Analysis**: “Analysis of properties of the system under study by means of e.g. simulations or queries”
- **(Re-)Design**: “(Re-)design of future version of the system under study”

[25]Note: Sources mentioned in this paragraph refer to the whole list of bullet points below.

- **Code Generation**: "Generation of code (parts) that can be executed to realize a (software) system"

5.4.8 Conceptual Modeling Languages

The conceptual modeling languages used are recorded for each paper so that their popularity and application in combination with the further taxonomies could be analyzed later on. Among the over 120 conceptual modeling languages that appeared in the selected set of publications were *UML*, *ER*, *DSL*, *Petri Nets*, *BPMN*, *ArchiMate*, *Systems Modeling Language (SysML)*, *aml*, *OntoUML*, and *Object Constraint Language (OCL).*

5.4.9 Value Added of Combining SW and CM Taxonomy

When Semantic Web and Conceptual Modeling are brought together, they can add further value with regard to *Representation flexibility*, *Incremental schema and modeling*, *Interoperability of multimedia metadata*, and *Enhanced inference capabilities*, which is described in greater detail below [3] [31] [51] [5].

- **Representation flexibility**: "Any extant data structure or format can be represented as RDF. RDF can readily express information contained within structured (conventional databases), semi-structured (Web page or XML data streams), or unstructured (documents and images) information sources" [3].
- **Incremental schema and modeling**: "Semantic technologies, on the other hand, allow domains to be captured and modeled in an incremental manner. As new knowledge is gained or new integrations occur, the underlying schema can be added to and modified without affecting the information that already exists in the system. This adaptability is generally the biggest source of economic benefits to the enterprise from semantic technologies. It is also a benefit that enables experimentation and lowers risk" [3].
- **Interoperability of multimedia metadata**: SW technologies can help to make metadata from different, otherwise not compatible sources interoperable, and W3C standards using formal semantics can be used for this purpose [51] [31].
- **Enhanced inference capabilities**: SW technologies extend the reasoning capabilities of CM using formal logic (e.g. description logic) to make inferences based on ontologies. Models that include OWL and RDF(S) have the necessary formal foundations [31] [5].

5.5 Data Extraction and Mapping

In the last step of the systematic mapping study, according to Petersen (2008), the data is retrieved from the underlying databases, and is mapped to the taxonomies [42]. For this purpose, an online spreadsheet was created which contained the exported data in one tab, including the categorization per taxonomy with each taxonomy in one separate column respectively. In addition to this, one tab per taxonomy was created to give an early, short overview on the frequency per classification category.

	A	B	C	D	E	F
1	Database	Title	Authors	Authors_Short	CurrentUniversity	CurrentCountry
2	WoS	The role of foundational ontologies for conceptual ontology representation	Guizzardi, Giancarlo	Guizzardi	Free University of Bozen-I	Italy
3	WoS	A model driven approach for building OWL DL and	Brockmans, Saartje and Colomb, Robert M. and Elisa F. and Wallace. Evan K. and Weltv. Chris ar	Brockmans;Colomb;Haas	Ontoprise GmbH;The Uni	Germany;Australia;Gern
4	WoS	Insights on the Use and Application of Ontology ar Languages in Ontology-Driven Conceptual Modelir	Verdonck, Michael and Gailly, Frederik	Verdonck;Gailly	Universitair Ziekenhuis Br	Belgium;Belgium
5	WoS	A Model-Driven Approach for Describing Semantic to OWL-S	Kim, Il-Woong and Lee, Kyong-Ho	Kim;Lee	Yonsei University;Yonsei U	South Korea;South Kore
6	WoS	A Model-Driven Approach for Using Templates in (	Parreiras, Fernando Silva and Groener, Gerd an Staab. Steffen	Parreiras;Groener;Walter	Universidade FUMEC;Uni	Brazil;Germany;German
7	WoS	Semi-automated Generation of DSL Meta Models Ontologies	Ojamaa, Andres and Haav, Hele-Mai and Penja	Ojamaa;Haav;Penjam	Tallinna Tehnikaulikool;Ta	Estonia;Estonia;Estonia
8	WoS	First Workshop on Transforming and Weaving Ont Engineering (TWOMDE 2008)	Parreiras, Fernando Silva and Pan, Jeff Z. and A Henriksson. Jakob	Parreiras;Pan;Assmann;H	Universidade FUMEC;The	Brazil;United Kingdom;G
9	WoS	Model Driven Architecture Implementation Using	Cherkashin, Evgeny and Kopaygorodsky, Alexey Shigarov. Alexev and Paramonov. Viacheslav	Cherkashin;Kopaygorodsk	Irkutsk National Research	Russian Federation;Russ
10	WoS	Model-driven Approach to the Integration of Mult Semantic Web Services	Hahn, Christian and Nesbigall, Stefan and Warv Ingo and Klusch. Matthias and Fischer. Klaus	Hahn;Nesbigall;Warwas;Z	German Research Center	Germany;Germany;Gerr
11	WoS	Lifting metamodels to ontologies: A step to the se modeling languages	Kappel, Gerti and Kapsammer, Elisabeth and Ka Gerhard and Reiter. Thomas and Retschitzegge	Kappel;Kapsammer;Kargl;	Technische Universitaet V	Austria;Austria;Austria;A
12	WoS	Ontology definition metamodel based consistency	Wang, Shengjun and Jin, Longfei and Jin, Chen	Wang;Jin;Jin	Jilin University;Jilin Unive	China;China;China
13	WoS	Bridging together Semantic Web and Model-Drive	Alvarez Alvarez, Manuel and Pelayo G-Bustelo, Saniuan-Martinez. Oscar and Cueva Lovelle. Ju	Alvarez Alvarez;G-Bustelo	Universidad de Oviedo;Ur	Spain;Spain;Spain;Spain

Figure 5.5: Excerpt of data spreadsheet based on an approach by Bork (2022) [6]

After the data extraction, the data was cleaned, formatting was aligned, and integrity checks on the data were performed. The Figure 5.5 shows an excerpt of the data for the subsequent analysis phase, whose structure was inspired by Bork (2022) [6]. In this figure, the database, title, authors, short authors summary, current university and country of the researchers are the visible attributes 5.5. This was complemented by a series of further attributes such as the university and country where the researchers were located at the time of publication, their Scopus ID, the publication's abstract, year, document type, publication channel (i.e. source title), Uniform Resource Locator (URL), DOI, number of pages, relevant documents, as well as all taxonomies. The taxonomies comprised the W3C main areas of Semantic Web, the SW activity, semantic technology segments, SW standards, research and contribution type, modeling purpose, and value added by combining the two topics. Finally, a collection of conceptual modeling language as well as their acronyms were also saved to a separate tab. All in all, the dataset comprised 30 features for 484 publications.

CHAPTER 6

Findings

6.1 Overview on Findings

The chapter *Findings* 6 presents and discusses the results of the data analysis based on the extracted data from the 484 relevant publications at the intersection of conceptual modeling and Semantic Web. Prior to the analysis phase, the data was prepared along a series of cleaning steps to unify the institutions and researcher naming, and further integrity checks on the data were run. Subsequently, the publications data was analyzed and plotted using mainly Python and R. VOSviewer[1] was used to visualized the research community data in the form of knowledge graphs.

The chapter is divided into several parts, with the first one being the *Bibliographic Analysis* 6.2, which illustrates the overall evolution of publications in the research field under concern, the split between publication types, publication channels, countries, and contributing institutions.

Secondly, the *Content Analysis* 6.3 provides insights into the most frequently occurring technical terms as well as conceptual modeling languages used in the field of research. In addition to this, quantitative data stemming from the classification schemes is prepared in a visual way including analyses of the development over time.

The third part refers to the *Combined Analysis* 6.4 that considers combinations of taxonomies, i.e. along two dimensions, and in a three dimensional way over time. The findings in this part are mainly illustrated in the form of bubble plots in order to provide a comparable structure across the different combinations.

In the fourth and final part *Research Community Analysis* 6.5, the publications are reviewed with regard to communities of researchers and universities (incl. their countries of location) that publish together or are otherwise related. The analysis first takes an

[1]https://www.vosviewer.com/ (last accessed on 24 November 2022)

overall approach, then dives into the specific communities. Additionally, the development over time, the number of publications, and the number of citations are considered.

6.2 Bibliographic Analysis

The systematic mapping study considered publications ranging from the year 2005 to 2022. As Figure 6.1 shows, the number of publications at the intersection of conceptual modeling and Semantic Web has grown over the last two decades from around 3 to 10 publications in the 2000s to over 50 per year in the late 2010s. The trend is an overall positive one, with small exceptions in 2007, 2011, and 2015 (see Figure 6.1). In 2022, the 11 publications that are depicted have been published until May, so a larger number is expected for the entire year.

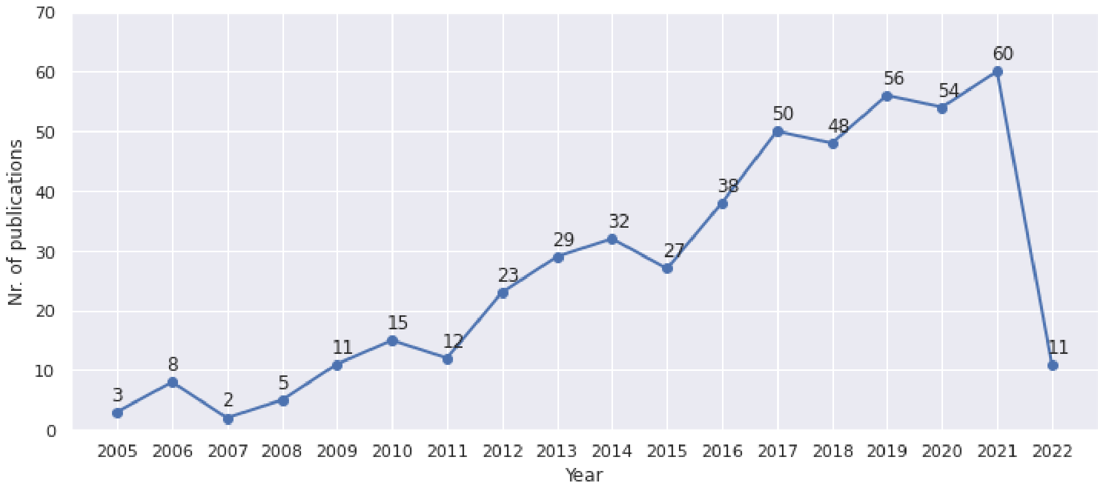

Figure 6.1: Nr. of publications per year

When it comes to the overall split of publications per type, Figure 6.2 shows that the largest part of them (i.e. 339) are conference proceedings, followed by 143 journal articles, and 2 book chapters. This indicates that the research area is still growing, as the larger part of research output is in conference proceedings rather than in formal journal articles or books.

Figure 6.3 splits the publications into type journal article and type conference paper, which shows that the number of conference papers has grown much faster than the number of journal articles up to the year 2019. This confirms the remark from before that the field was growing but not yet maturing until then. Since 2019, the number of conference proceedings published has come down to a level similar to the number of journal articles, which indicates that the research in the field is starting to mature in recent years (see Figure 6.3). For reasons of simplicity and better visibility of the remaining categories, the two book chapters were not shown in Figure 6.3.

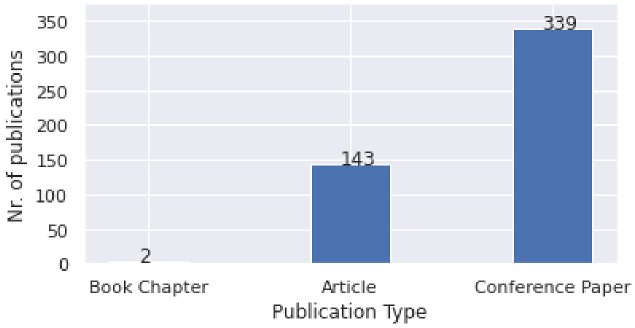

Figure 6.2: Nr. of publications per type

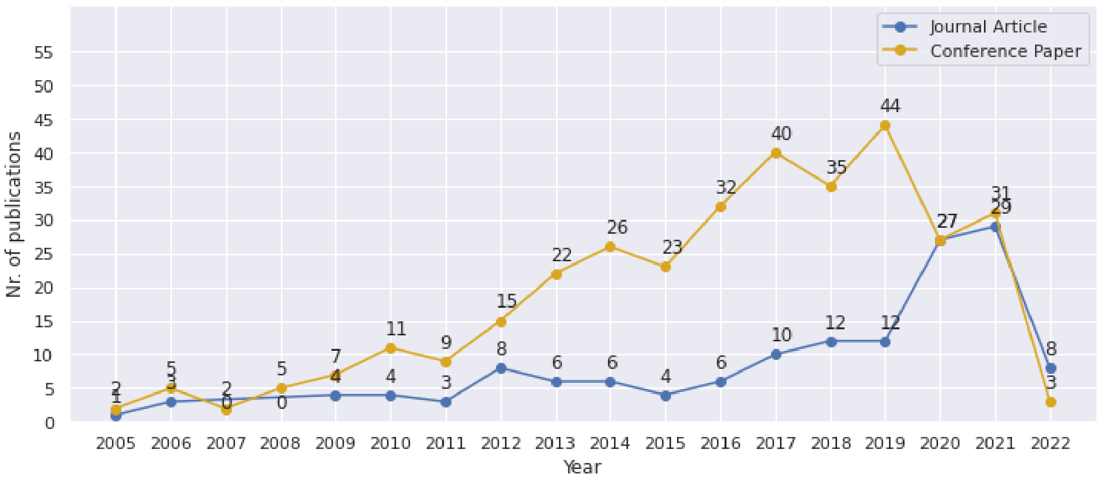

Figure 6.3: Nr. of publications per year and type

After a review of the publications list, it turned out that the countries mentioned in Table 6.1 were the top 10 contributors based on the number of researchers mentioned as authors of the publications, counting the number of researchers even if several authors worked in institutions in the same country. Among the top countries in terms of researchers are China, Germany, the USA, France, Brazil, Italy, Spain, Austria, Russia, and the UK in this specific order (see Table 6.1).

After a review of the publications list, it turned out that the countries mentioned in Table 6.2 were the main contributing countries based on the number of papers when counting the country only once per paper (even if several authors worked in institutions in the same country). The list of top countries based on the number of publications is very similar to the one based on the number of researchers, with slight changes after the top 3, namely between Brazil and France, then Austria and Spain, and between the UK and Russia, according to Table 6.1 and 6.2.

When one takes the transition from the country level to the institution level, Table 6.3

Country	Number of authors
China	247
Germany	186
United States	147
France	94
Brazil	79
Italy	78
Spain	70
Austria	49
Russia	48
United Kingdom	46

Table 6.1: Main contributing countries based on nr. of authors

Country	Number of publications
China	69
Germany	68
United States	46
Brazil	34
France	31
Italy	29
Austria	26
Spain	24
United Kingdom	22
Russia	16

Table 6.2: Main contributing countries based on nr. of publications

lists the top 10 institutions in terms of number of researchers count overall. The Federal University of Espirito Santo from Brazil stands out with 45 person occurrences among the papers, followed by a series of European and Middle Eastern universities with 28 to 15 contributors to publications, and finally the Beijing Institute of Technology as the number 10 organization in terms of researchers in this research area (see Table 6.3).

The top 10 institutions in terms of number of publications count are depicted in Table 6.4. The Federal University of Espirito Santo from Brazil and the University of Vienna from Austria stand out with over 20 publications each, followed by the Free University of Bozen-Bolzano (Italy), Babes-Bolyai University (Romania), and Vienna University of Technology (Austria) with at least 10 publications each, according to Table 6.4. Compared to Table 6.3, this list of institutions (see Table 6.4) has only partial overlaps, while also the ranking is largely different, depending on the criterion considered as a basis for counting.

Institution	**Country**	**Number of researchers**
Federal University of Espirito Santo	Brazil	45
Kaunas University of Technology	Lithuania	28
Free University of Bozen-Bolzano	Italy	24
Hassan II University of Casablanca	Morocco	21
Babes-Bolyai University	Romania	21
Ege University	Turkey	20
University of Leipzig	Germany	18
Vienna University of Technology	Austria	17
University of Vienna	Austria	15
Beijing Institute of Technology	China	15

Table 6.3: Top 10 contributing institutions based on nr. of researchers

Institution	**Country**	**Number of publications**
Federal University of Espirito Santo	Brazil	23
University of Vienna	Austria	21
Free University of Bozen-Bolzano	Italy	14
Babes-Bolyai University	Romania	10
Vienna University of Technology	Austria	8
Kaunas Institute of Technology	Lithuania	8
University of Leipzig	Germany	7
Wuhan University	China	7
Karlsruhe Institute of Technology	Germany	6
Polytechnical University of Valencia	China	6

Table 6.4: Top 10 contributing institutions based on nr. of publications

The number of times the countries were mentioned in terms of researchers compared to publications (with counting a country only once per paper), the Figure 6.4 shows that although the ranking is slightly different among the top 10, the main contributing countries are the same in both analysis scenarios, namely China, Germany, USA, Brazil, France, Italy, Austria, Spain, UK, and Russia.

The main publication channels for the publications at the intersection were conference proceedings and journal articles, as Figure 6.2 showed earlier. As for the journal articles, the journals in which the topic has been most prevalent are depicted in Table 6.5. The *Journal of Biomedical Informatics*, *Expert Systems with Applications*, and *IEEE Transactions on Services Computing* were among the top 3 journals as publication channels.

With reference to the category conference proceedings among the publication channels, the top conference, in line with which the largest number of publications were presented

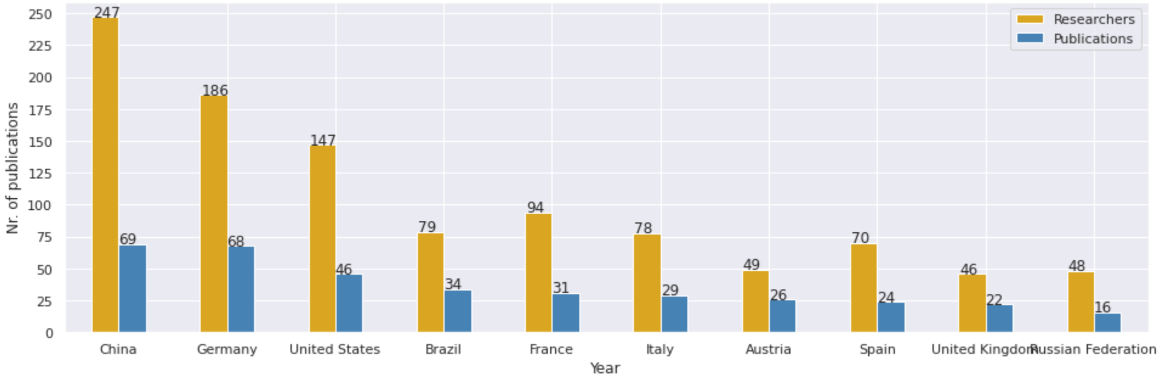

Figure 6.4: Top 10 countries based on nr. of researchers and publications

Publication channel (journal)	Number of journals
Journal of Biomedical Informatics	6
Expert Systems with Applications	5
IEEE Transactions on Services Computing	5
Journal of Systems and Software	4
Semantic Web	4
Applied Sciences	4
Data and Knowledge Engineering	4
Information Systems	3
IEEE Access	3
Advanced Engineering Informatics	3
Advances in Production Management Systems	3

Table 6.5: Publication channels: top journals

are shown in Table 6.6. *Conceptual Modeling, ER* was the leading conference among the analyzed publication channels, followed by the *IEEE International Conference on Engineering Technologies and Factory Automation*, and the *Winter Simulation Conference*.

6.3 Content Analysis

The section *Content Analysis* 6.3 contains analyses based on the taxonomies considered independently and over time, as well as the abstracts of the relevant publications.

The content of the abstracts of the selected publications was analyzed in the form of a word cloud, which is illustrated in Figure 6.5. The terms *ontology*, *Semantic (Web)*, *knowledge*, *metamodel*, *modeling language*, *concept(ual modeling)*, *domain*, *method*, *design*, *formal*, *development*, *UML*, *OWL*, and *process* stand out in the word cloud (see Figure

Publication channel (conference)	Number of conferences
Conceptual Modeling, ER	17
IEEE Conference on Emerging Technologies & Factory Automation	6
Winter Simulation Conference	5
Model and Data Engineering	5
Conference on Model-Driven Engineering & Software Development	5
IEEE Enterprise Distributed Object Computing Workshop	4
Conference on Knowledge Discovery, Engineering & Management	4
Semantic Web	3
Procedia Computer Science	3
IEEE Aerospace Conference	3
Federated Conference on Computer Science & Information Systems	3
International Semantic Web Conference	3

Table 6.6: Publication channels: top conferences

6.5). This collection of most frequently occurring words gives a concise overview of what terms are crucial at the intersection of conceptual modeling and Semantic Web, and therefore capture its essence well.

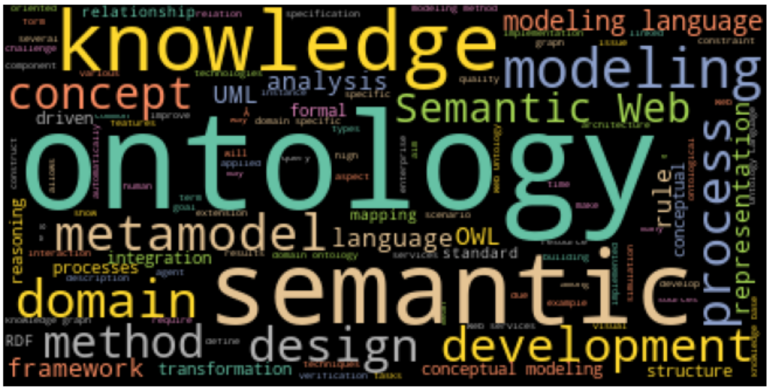

Figure 6.5: Word cloud based on abstracts

Figure 6.6 illustrates the development of the number of publications split by research type over time from 2005 to May 2022, which indicates that the publications in each category have increased. The major part is formed by publications of the solution type, i.e. it presents a "new solution or extension of existing solution to a problem, whose applicability is shown by an example or a solid argumentation", which rose fast from the 2010s onwards compared to all other types [41] [42]. The evaluation and the experience type also experienced rather steady, but not high growth, as shown in Figure 6.6. The vision type, i.e. "non-disruptive research agenda setting papers", grew up to around 2017, and then declined [63].

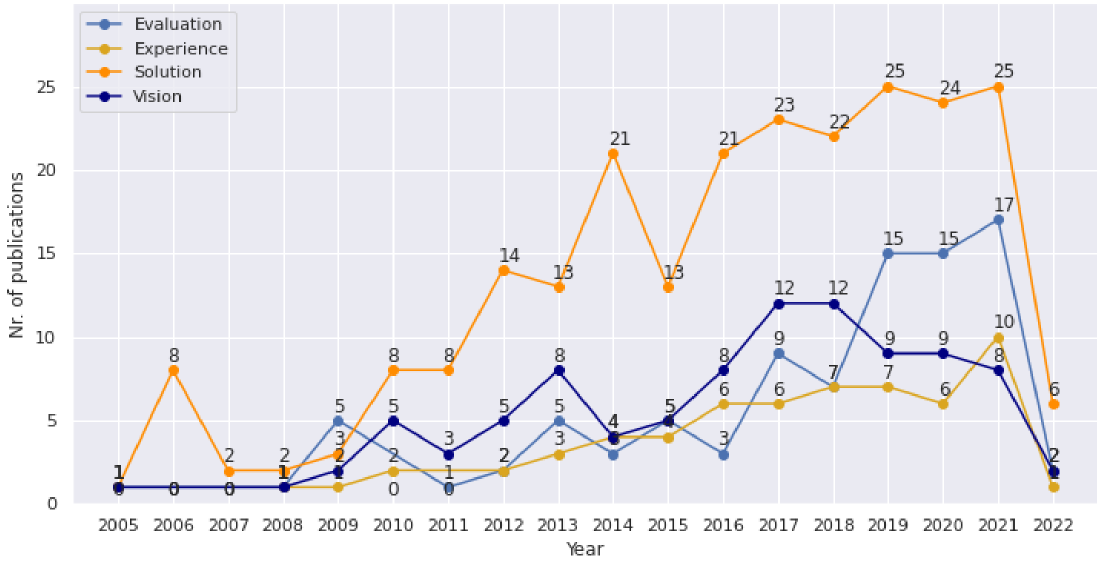

Figure 6.6: Nr. of publications per year and research type

With regard to the contribution type, the number of publications has developed differently depending on the category of contribution type, which is illustrated in Figure 6.7. The largest part of publications have recently appeared to provide new or adaptations of existing methods in terms of contribution type, which considerably increased in numbers over the last two decades. The number of concepts has not frequently been among the largest types, but has recently become more popular, and came in second in 2021, according to Figure 6.7. The number of discussions peaked in 2017 to 2018, but has since declined again, while the publications presenting algorithms or tools have been growing in recent years, but at a lower level, as depicted in Figure 6.7.

As for the conceptual modeling part of the intersection topic, Figure 6.8 shows that UML is by far the most frequently used conceptual modeling language, followed by any kind of DSL, and BPMN which is suited to business processes. Furthermore, Semantic Web Rule Language (SWRL), OntoUML, SysML, ER, OCL, knowledge graphs in general, and ADONIS were among the top 10 conceptual modeling language (CML) used in the list of selected publications for this SMS out of over 100 conceptual modeling languages that were mentioned in the publications.

In the next step, the modeling purpose taxonomy was applied to the publications, and analyzed over time as Figure 6.9 shows. According to Figure 6.9, the publications were split into four categories, which revealed representation and analysis as the most recent major modeling purposes among the publications. These two categories were leading the modeling purpose most of the time period analyzed, but not all as exceptions occurred in the early 2010s, and around 2018 to 2019 (see Figure 6.9). Code generation as a modeling purpose rose before 2015, then shortly declined, and finally rose again up to 2019, to

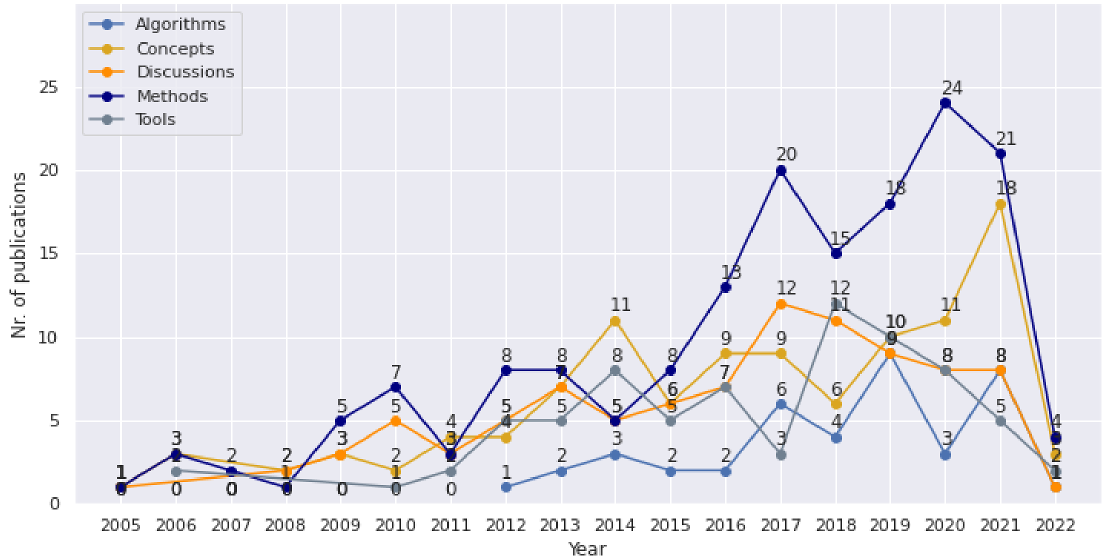

Figure 6.7: Nr. of publications per year and contribution type

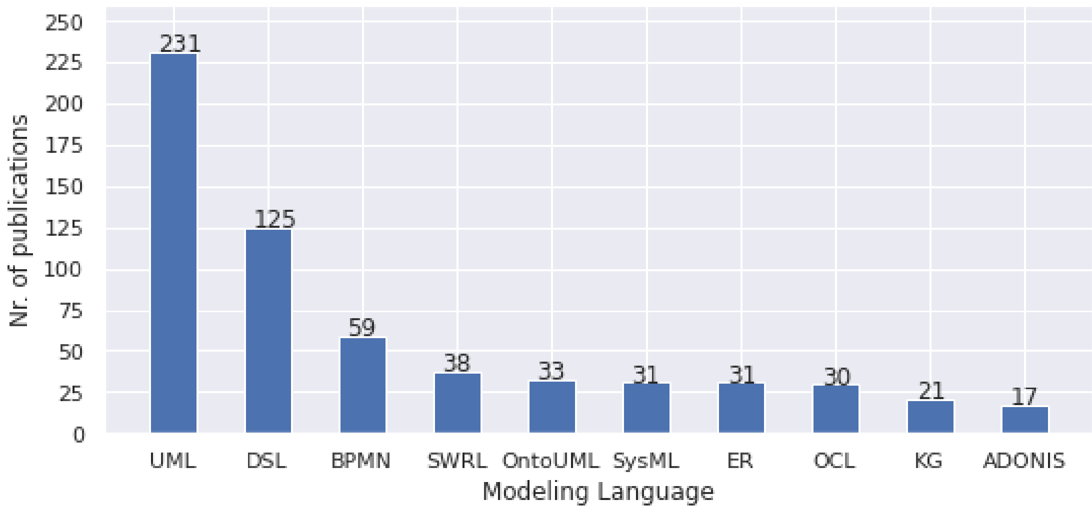

Figure 6.8: Top 10 modeling languages (out of >100)

then decline again. (Re-)Design as a modeling purpose occurred at a low level, but never considerably increased.

When considering the W3C main areas of Semantic Web overall, the largest part of the papers were related to *linked data* and *vocabularies*, while only a lower share can be attributed to *inference*, and *queries*, as Figure 6.10 illustrates.

The picture is still quite similar once the time component is also considered, as Figure

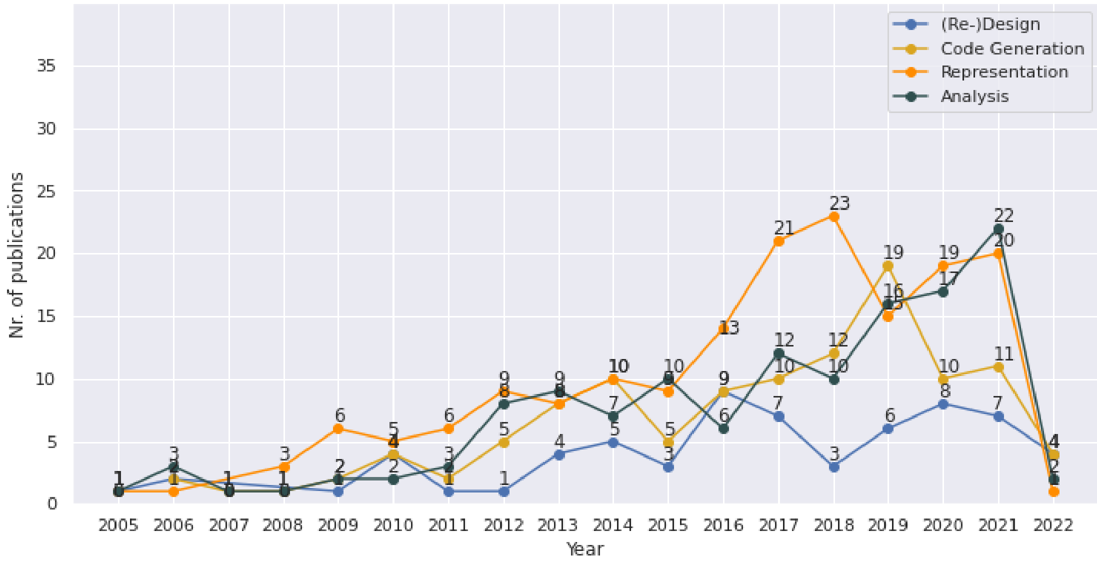

Figure 6.9: Nr. of publications by modeling purpose

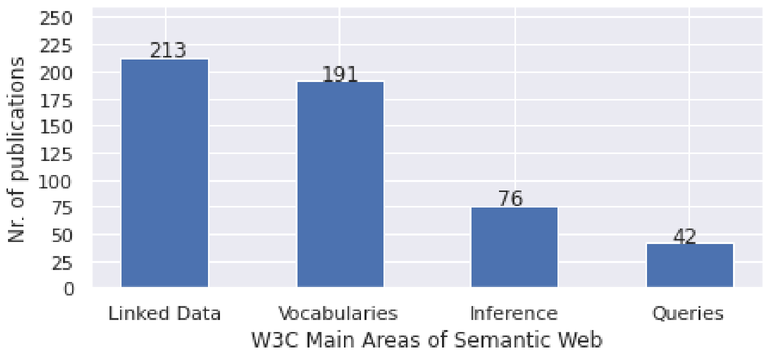

Figure 6.10: Nr. of publications by W3C main area

6.11 shows. In the mid-2000s, all categories started from a low level, while the number of publications on *linked data* and *vocabularies* increased considerably after 2011, the number of publications on *inference* and *queries* achieved merely a slightly higher level in this time period. It also has to be added at this point that the development of the number of publications in each one of the categories was not steady, but exhibited several increases and decreases (see Figure 6.11).

In line with the semantic technology segments, the overall by far most frequently occurring one (i.e. in 286 publications) is *semantic modeling and development* which involves "tools for design and development of all kinds of semantic services applications" [59] [25]. 121 publications dealt with *learning and reasoning* (i.e. inference theories and engines), 104 with *semantic data management and integration*, and 95 with *semantic annotation* (i.e.

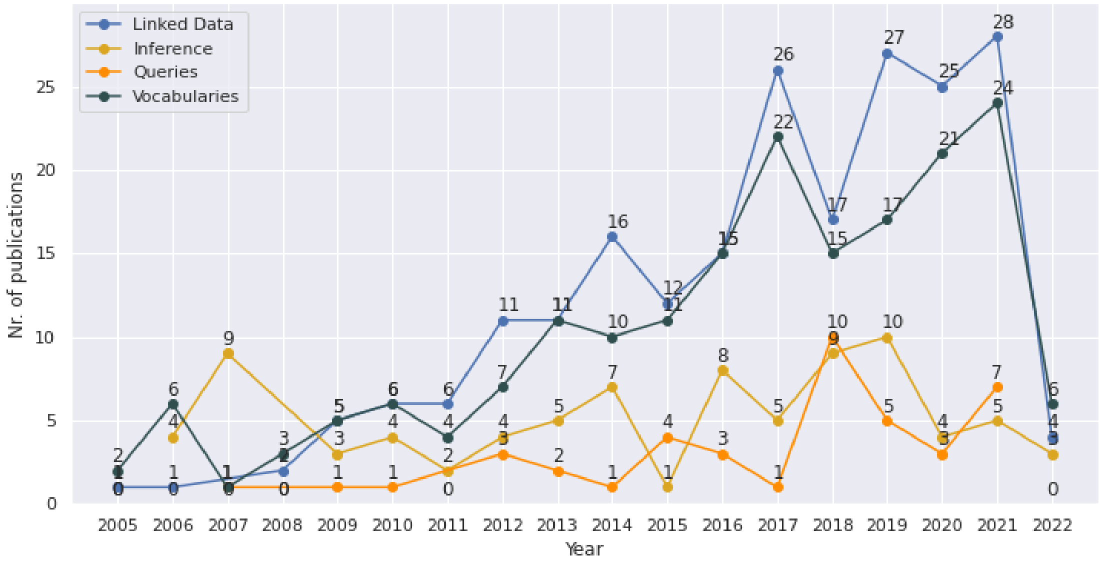

Figure 6.11: Nr. of publications by W3C main area and year

adding or extracting meaning from text or other underlying data) [59] [25]. The lowest number of publications, i.e. 35 individual papers, contained content related to *semantic search and retrieval*.

The 484 publications considered for this systematic mapping study were spread across different Semantic Web activity areas, which means industries or domains, as Figure 6.13 shows. The publications were categorized either in *foundational* or specific industry background works. One publication was assigned to only one Semantic Web activity area. Figure 6.13 shows that 187 out of the 484 publications, i.e. 38.6%, were of foundational nature, while the remaining 61.4% are split across specific domains. Among most prevalent domains-specific Semantic Web activity areas are *manufacturing*, *information technology (IT)*, *healthcare*, *education*, *GIS*, *cultural*, and *government* in this given order, according to Figure 6.13.

The number of publications can also be analyzed along the Semantic Web standard taxonomy, which revealed in Figure 6.14 that the largest part of the publications were related either to *OWL* or *RDF* or both. With regard to this taxonomy, it should be noted that one publication could refer to either one, several, or even none of the standards. The next most occurring SW standards among the publications were *SPARQL*, *RDFS*, *JSON-LD*, and *RIF*, according to Figure 6.14. The SW standards *SKOS*, *RDB2RDF*, *SHACL*, *SAWSDL*, and *RDFa* appeared to be used not so frequently, as illustrated by Figure 6.14. 111 out of the 484 publications did not contain any reference to a Semantic Web standard from the taxonomy. This does, however, not necessarily mean that they did not relate to any standard, but that just in the abstract, title, and full text no standard was mentioned.

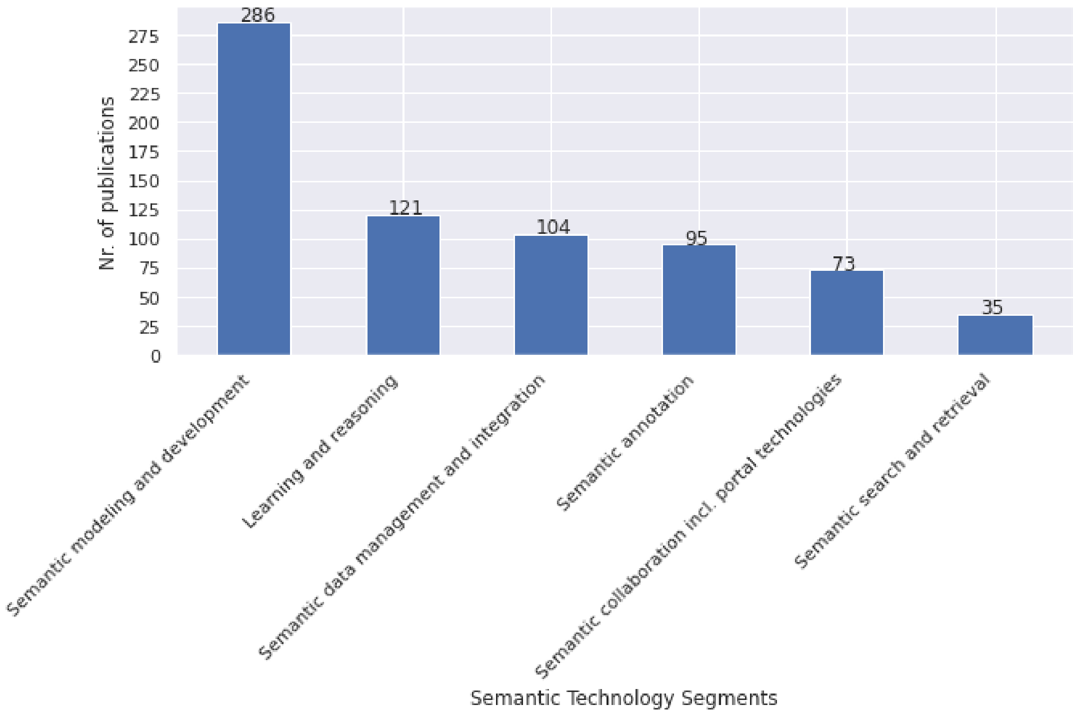

Figure 6.12: Nr. of publications by technology segment

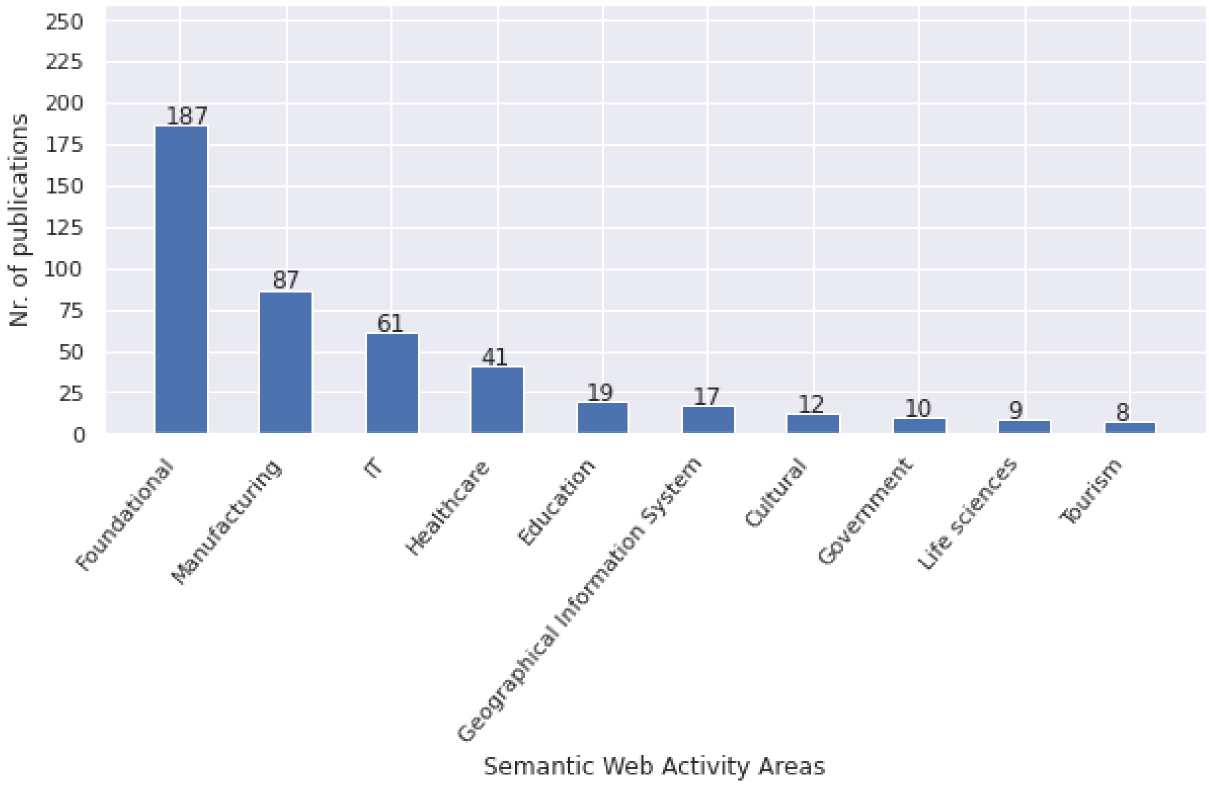

Figure 6.13: Nr. of publications by SW activity area

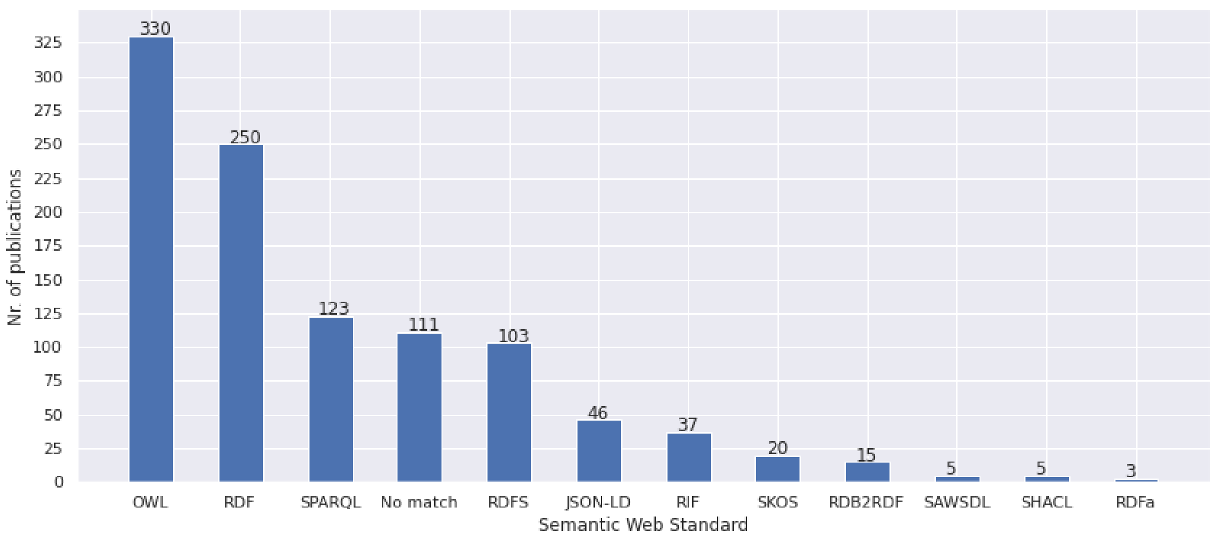

Figure 6.14: Nr. of publications by SW standard

6.4 Combined Analysis

The combined analysis considers both the value of combining Semantic Web and conceptual modeling, and the combination of several taxonomies in the form of bubble plots as well as their development over time.

With respect to the value added that can be achieved by combining SW and CM, Figure 6.15 illustrates that the leading value added can be realized in the form of *incremental schema and modeling* (appearing in 327 out of the 484 publications), so that models and schemas can be build gradually "without affecting the information that already exists in the system" which in turn decreases risk [3]. As this taxonomy is not exclusive, one publication could contain one or several main value benefit(s). 166 publications provide *interoperability of multimedia metadata*, 135 *representation flexibility*, and 118 *enhanced inference capabilities* as a value added of combining Semantic Web and conceptual modeling as illustrated by Figure 6.15.

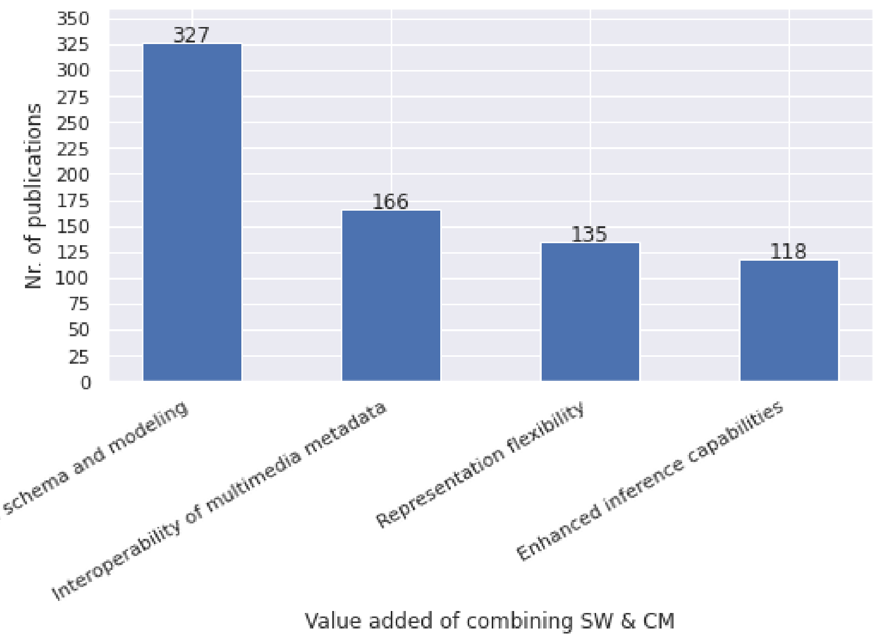

Figure 6.15: Value added by combining SW and CM

Over time, the value added taxonomy elements have evolved quite similar to the overall picture shown in Figure 6.15. The *incremental schema and modeling* evolved fastest among the different value added options, and peaked in 2021 with 49 publications, as Figure 6.16 depicts. The remaining three value added elements have developed over time from around two to three per year to around 15 to 20 each per year up to 2021, but their prevalence changed depending on the year which is illustrated by 6.16.

The bubble plot in Figure 6.17 combines the W3C main areas of Semantic Web with the

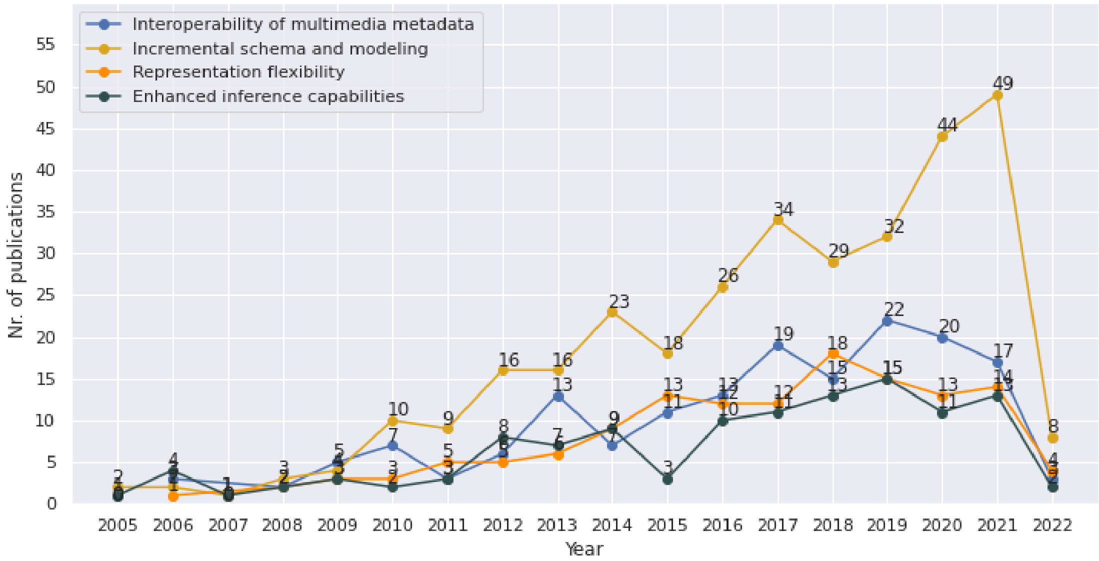

Figure 6.16: Value added by combining SW and CM over time

modeling purpose, which shows that the highest number of publications occurs along *representation* as purpose combined with *linked data*, or with *vocabularies*. Based on the data, it can be said from the Figure 6.17 that combinations of modeling purpose with *linked data* and *vocabularies* are more widespread rather than with *inference* or *queries* among the publications analyzed.

To add the time component, the combinations have also been analyzed in the form of bubble plots using once the publications before 2015 (on the left in orange), and in or after 2015 (on the right side in blue), as it can be seen from Figure 6.18. The development over time indicates that combinations of modeling purpose with *inference* or *queries* have tendentially stayed at a similar level or decreased, but combinations with *linked data* in general and *vocabularies* have increased considerably, according to Figure 6.18.

Figure 6.19 illustrates the combination of the contribution type with the modeling purpose taxonomy, which indicates a concentration of papers along *representation* modeling purpose combined with *discussions* or *concepts* contribution type. The contribution type of *methods* rather appears in combination with the modeling purpose of *code generation* or *analysis*, and the contribution type *tools* is mostly combined with *code generation* as a modeling purpose. Over time notably the combination of *methods* with *representation* have grown considerably, as well as in general all of the largest combinations mentioned above. However, the combinations of taxonomy elements in the lower left corner of the Figure 6.19 exhibited a significant decrease over time.

The taxonomy combinations of W3C main area with conceptual modeling language from Figure 6.20 reveals that the main areas *inference*, *linked data* and *vocabularies* are very often combined with the conceptual modeling language *UML* which is a general-purpose

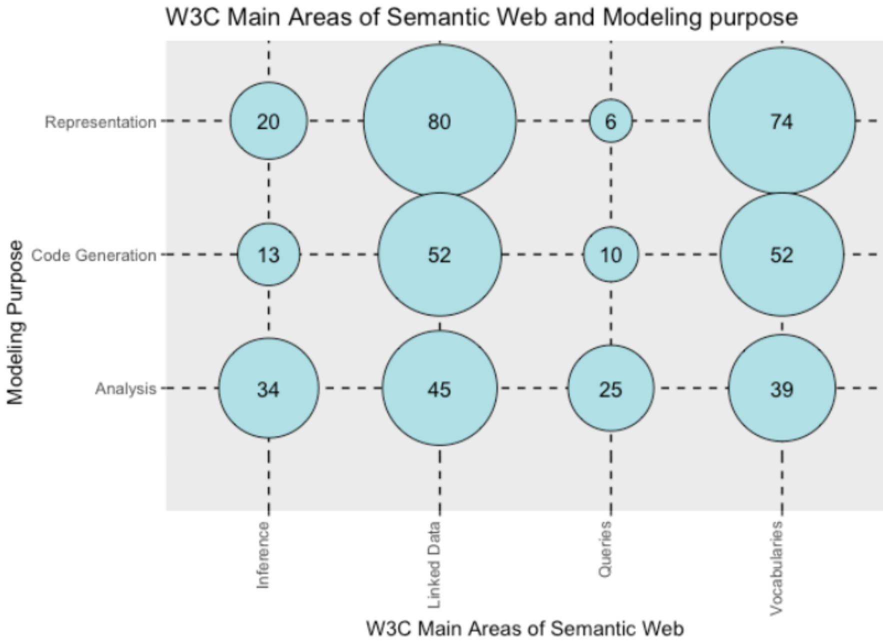

Figure 6.17: Nr. of publications by W3C main area and modeling purpose

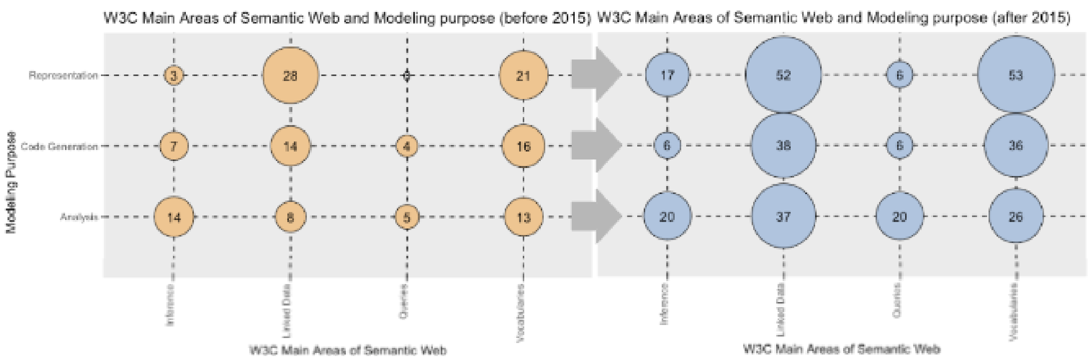

Figure 6.18: Development of taxonomy combination over time

modeling language. In addition to this, DSL also appear to be used widely with regard to *linked data*, and *vocabularies*. The increase in the use of *DSL* in these combinations almost tripled over time, whereas the use of *UML* only doubled. The evolution over time hinted towards a growth in *inference* main area together with CML such as OntoUML, OCL, ER, DSL, Automation Modeling Language (AML) and BPMN, as well as with *queries* in combination with UML, ER, and DSL.

When it comes to the combination of Semantic Web standards with conceptual modeling languages, it appears that UML, DSL, and BPMN as CML stand out in combination with the Semantic Web standards OWL, RDF, RDFS, and SPARQL, as Figure 6.21 depicts.

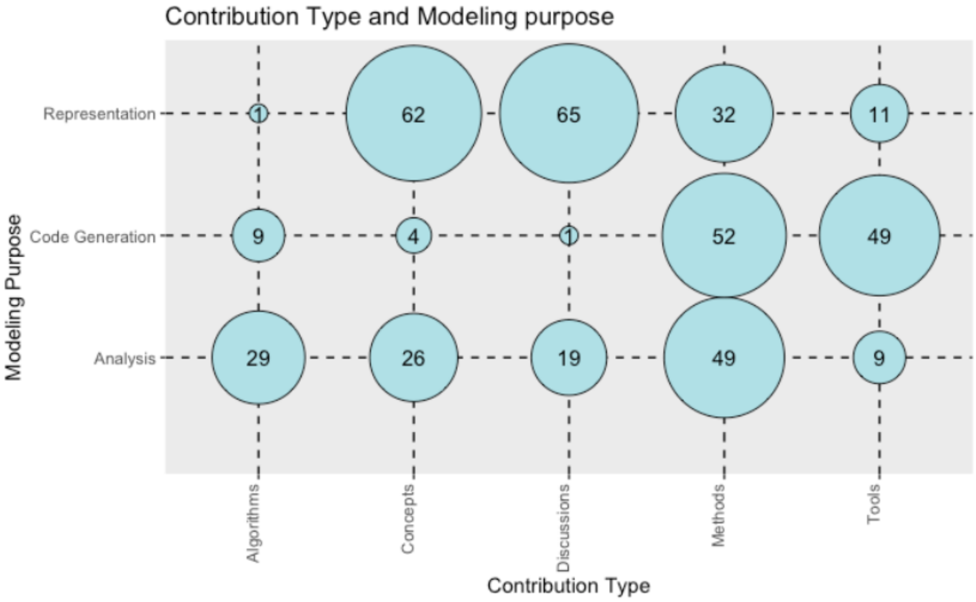

Figure 6.19: Nr. of publications by contribution type and modeling purpose

Over time, all of those main combinations have increased considerably, and additionally the standard JSON-LD became visible more frequently in combination with UML, ER, OntoUML, DSL, and BPMN. The combinations with the Semantic Web standards RIF, RDB2RDF, and SKOS slightly increased over time, whereas those with SAWSDL which only existed for UML and BPMN in the first place disappeared over time.

With respect to the combination of research type and conceptual modeling language taxonomies, it can be seen from Figure 6.22 that the highest number of publications occurred at the combination of *UML* and *solution* research type, followed by the combination of *DSL* and *solution*. In general, UML exhibits a high number of publications in combination with all researcher types, just like DSL does. The analysis over time also revealed that the highest number of publications has been located along the *solution* research type, whereby it was split quite evenly between the remaining research types. UML has at least doubled in size over time from before 2015 to the time after 2014, and the same tendency was also observed regarding DSL and BPMN in all combinations, although at a lower level. The modeling language *SysML* in combination with the *solution* research type increased four times over time from 3 to 12 in the observed time periods. In contrast to this, Petri Nets, OntoUML, and OCL increased in combination with *evaluation*, *experience*, and *solution* research types. ArchiMate and Petri Nets remained overall at a quite low level.

In Figure 6.23, the combination of contribution type and conceptual modeling language is considered, and additionally analyzed over time. The overall view in Figure 6.23 shows that the conceptual modeling language UML stands out in its combinations with *methods*,

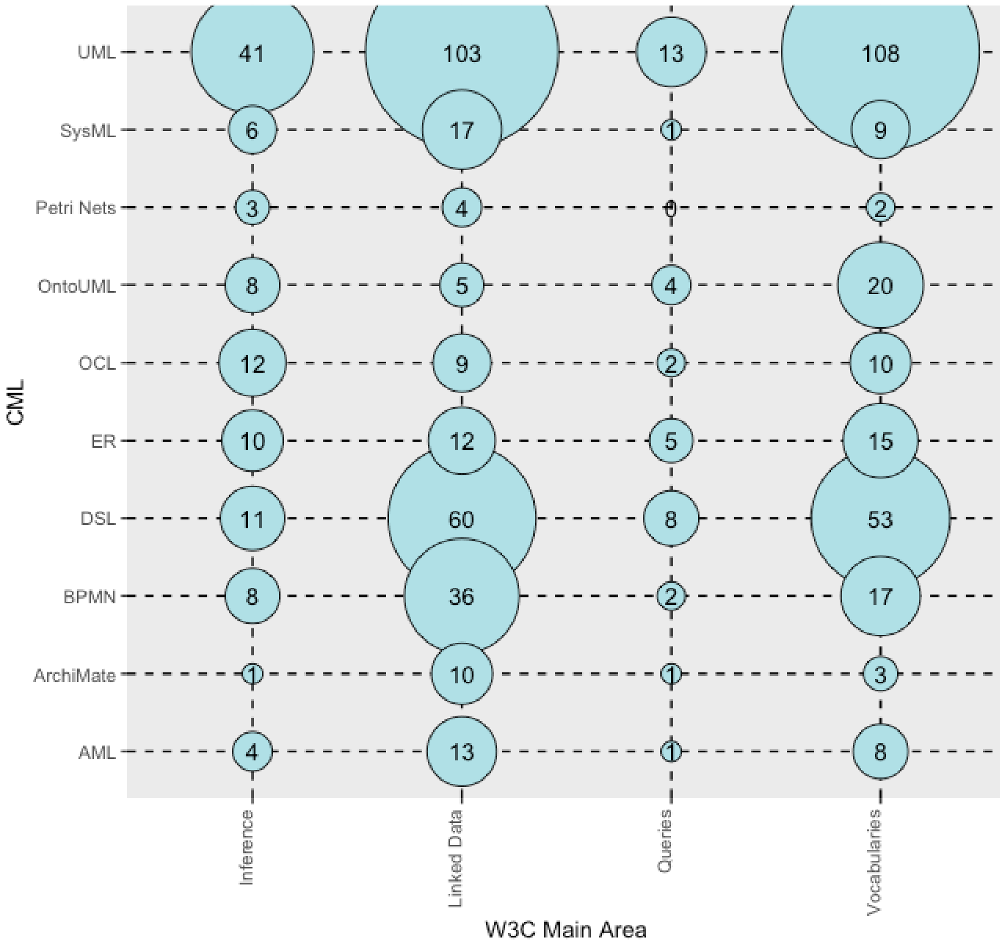

Figure 6.20: Nr. of publications by W3C main area and CML

concepts, and *discussions* in terms of number of publications. This is also apparent with DSL and the same combinations, which represent the majority of combinations that occur along those two taxonomies. Over time, the highest growth happened with regard to UML in combination with all contribution types, notably *methods*, and the second highest increase in DSL combined with *methods* as well. *Algorithms* as a contribution type have grown considerably in combination with UML and DSL, but not with other conceptual modeling languages over time. The research type *concepts* grew as such, but notably well with OntoUML, OCL, ER, and BPMN. *Discussions* grew with regard to all conceptual modeling language with the exception of OCL. The research type *methods* has been on the rise as well on all conceptual modeling languages, notably UML, DSL, and BPMN. The category *tools* became larger over time for all but *Petri Nets* and AML.

Concerning the combination of the modeling purpose and conceptual modeling language taxonomies, Figure 6.24 illustrates that the largest number of publications occur for the CML UML and DSL in combination with the modeling purpose types *representation*,

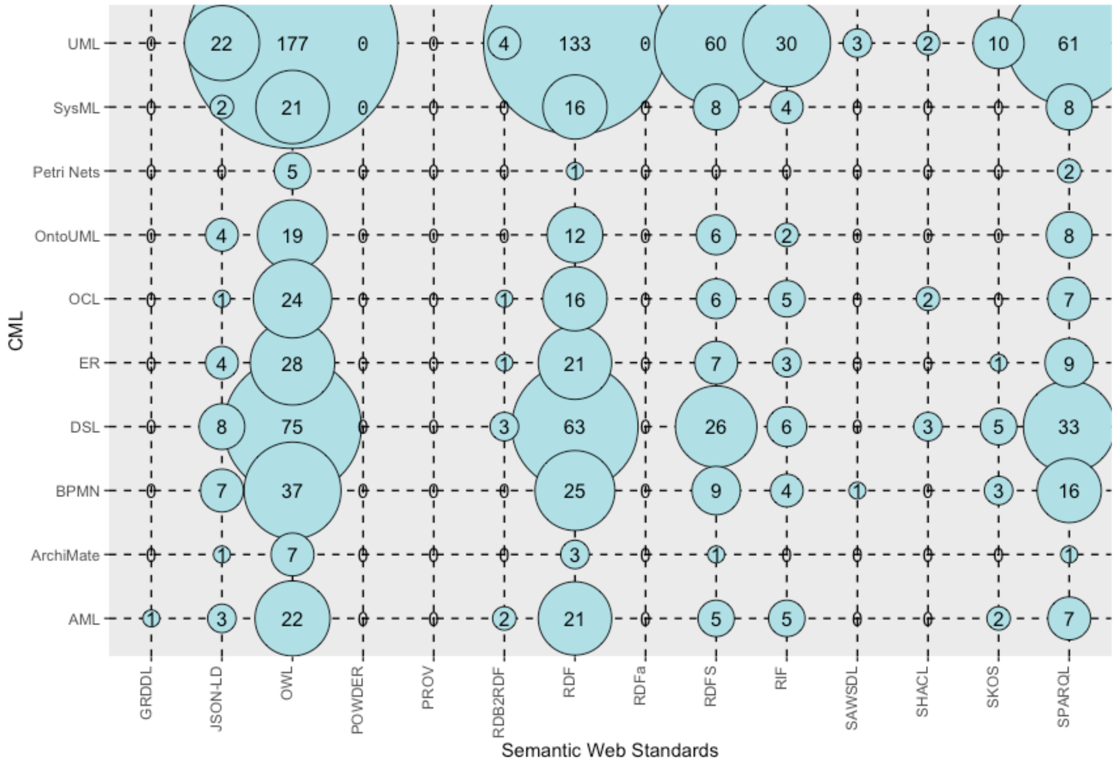

Figure 6.21: Nr. of publications by W3C standard and CML

analysis, and *code generation*. The next biggest combined groups occur in the *representation* type with OntoUML, OCL, ER, BPMN, and ArchiMate. In the *code generation*, the next largest combinations appear with BPMN, AML, and ER. In the *analysis* type, the combinations with OCL, ER, OntoUML, and AML are the next biggest.

Over time UML more than doubled with regard to all modeling purposes, and DSL has grown even stronger than UML. SysML halved with regard to the modeling purpose *analysis*, but considerably increased for *code generation*, and *representation*. Petri Nets, OntoUML, OCL, AML, and ER have remained almost stable at a low level or increased slightly. ArchiMate in combination with *analysis* has not been represented in the later time period any more, but has grown in the *code generation* and *representation* purpose area.

In the overview presented in Figure 6.25, the largest number of publications concentrate at the combination of firstly UML and secondly DSL with all kinds of value added opportunities. BPMN combined with the value added types *incremental schema and modeling*, *interoperability of multimedia metadata*, and *representation flexibility* accounts for a large part of combinations in Figure 6.25. The combinations related to OntoUML, OCL, ER, ArchiMate, and AML are at a lower range from around 5 to 15 publications per combination, but are quite evenly spread across the value added options. As for

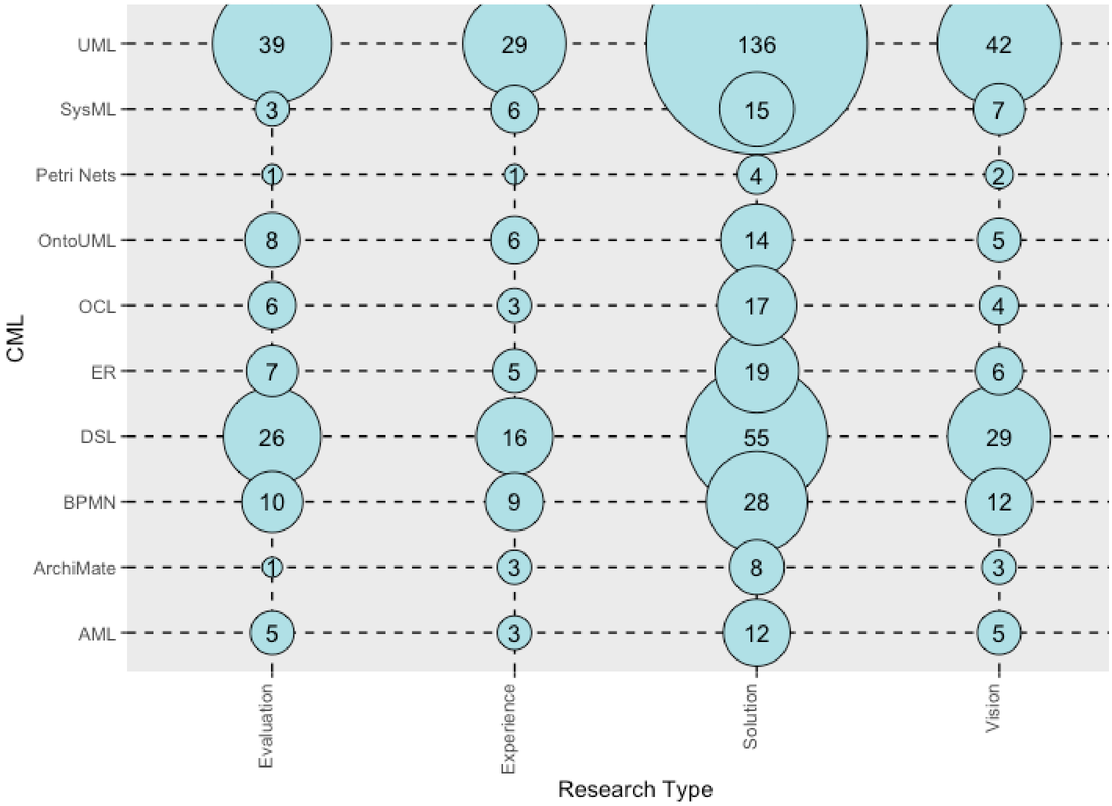

Figure 6.22: Nr. of publications by research type and CML

the development over time, the strongest growth was observed in UML, and DSL both combined with *incremental schema and modeling*, and UML with *interoperability* as well as *representation flexibility*. Comparatively low growth was recorded for Petri Nets, ArchiMate, OCL, and ER overall. The *enhanced inference capabilities* have recorded major growth in combination with OCL, ER, DSL, BPMN, and AML. In the value added taxonomy element *incremental schema and modeling*, the use of DSL, UML, BPMN, and OntoUML has surged over time. With regard to *interoperability*, major growth has occurred in BPMN, even larger than DSL, and at the same time the use of the remaining CML has increased to a smaller extent (ranging between five and ten publications per year). As for *representation flexibility* as a value added category, it has grown for ArchiMate, AML, and OntoUML, but has stayed stable at a low level for ER, OCL, and Petri Nets.

Considering the taxonomy combination of W3C main area and research type illustrated in Figure 6.26, the highest number of publications occur overall in the combinations of *solution* research type and *linked data* or *vocabularies* main area. In general, the number of publications in the *linked data* main area appears to be the highest, followed by the ones in *vocabularies*. As for the *inference* main area, only the research type *solution* is

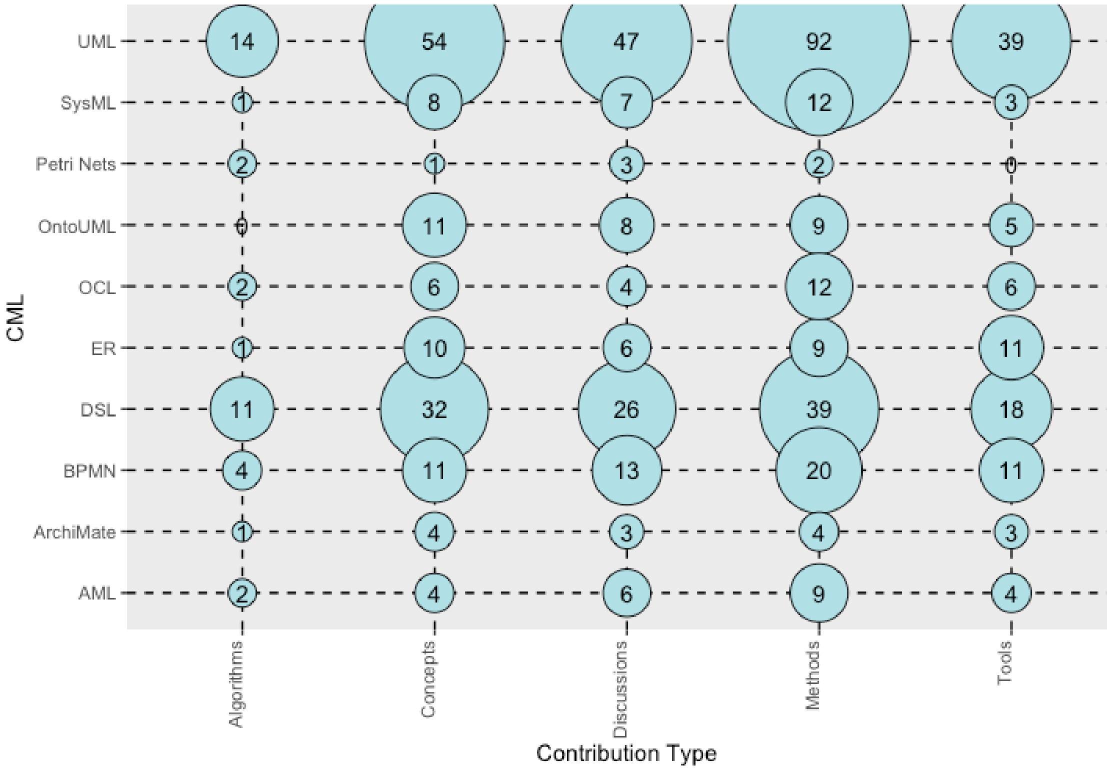

Figure 6.23: Nr. of publications by contribution type and CML

frequently occurring among the publications, and the remaining research types are rather rare compared to other combinations. In line with the main area *queries*, the largest combinations appear with the *evaluation* and the *solution* research type, as Figure 6.26 depicts, although the numbers are relatively small compared to the other W3C main areas. In line with the analysis of the number of publications over time, the combination of the main area *inference* with the research type *solution* decreased, while all other combinations of the main area *inference* with research types have increased. The W3C main area *linked data* has grown significantly in combination with all research types over time. The W3C main area *queries* have experienced a high growth, but at a lower level of around 5 to 10 publications, compared to over 60 for instance for the main areas *linked data* or *vocabularies* with the research type *solution.* In line with the main area *vocabularies*, the largest combination is with the research type *solution*, followed by *evaluation*, *experience*, and *vision*. *Experience* has developed significantly from 1 to 20 publications from before 2015 to after 2014, whereas *vision*, *solution*, and *evaluation* have grown at a lower scale.

The combination of the value added and the modeling purpose taxonomy is depicted in Figure 6.27. The largest number of papers was published along the combination of the modeling purposes *representation*, *code generation*, *analysis* and the value added opportu-

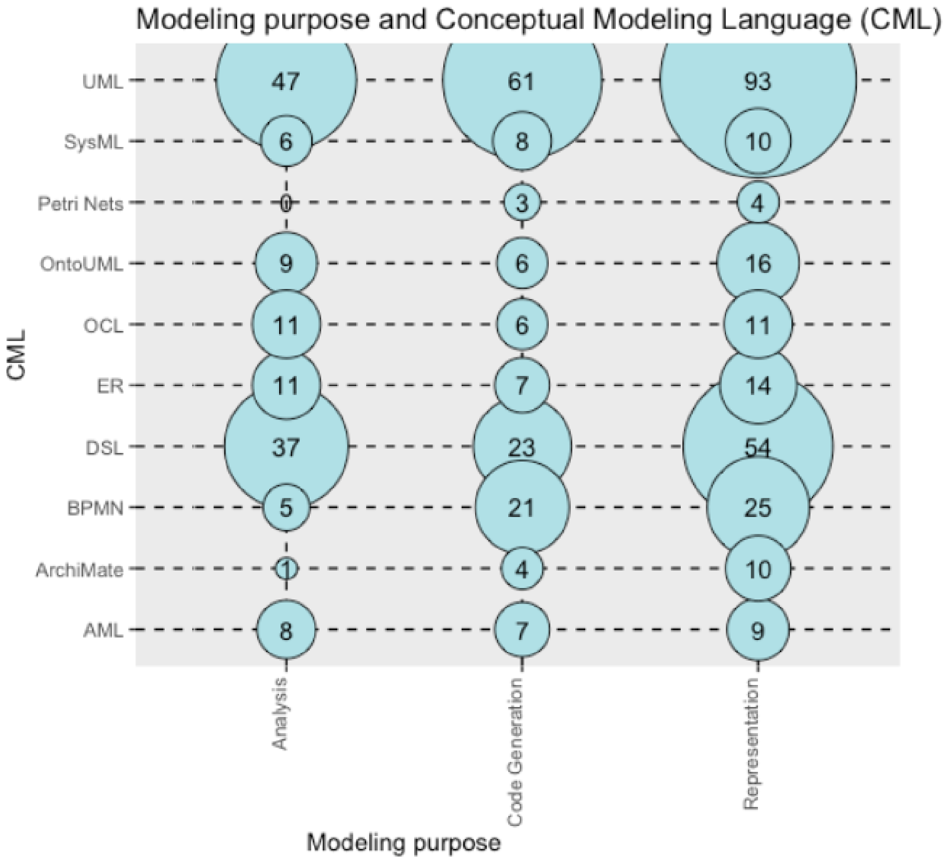

Figure 6.24: Nr. of publications by modeling purpose and CML

nity *incremental schema and modeling*. Over the observed time periods, all combinations (except for the modeling purpose *(Re-)Design*) have developed positively. The largest number of publications occurred in both time periods in the combinations of the value added opportunity *enhanced inference capabilities* with the *modeling purpose* of *analysis*, next to the combination of *representation* and *code generation* with *incremental schema and modeling*, and *representation flexibility* with *representation*. The combination of the value added of *representation flexibility* and modeling purpose *analysis* did practically not exist in the earlier time period (i.e. before 2015), but then developed fast into a rather large cluster. Similarly, the combinations of *representation* and *code generation* modeling purpose with the value of *enhanced inference capabilities*, of *analysis* modeling purpose with *interoperability*, and *code generation* with *representation flexibility* has grown from around 6 to 7 publications in the earlier time period to around 15 to 20 in the later one.

The combination of the Semantic Web activity areas with the modeling purpose taxonomy is finally depicted in Figure 6.28. An integral part of the publications concentrates in the foundational activity area in combination with the modeling purposes *representation* (79 publications), *analysis* (57), and *code generation* (39). Notably the modeling purposes

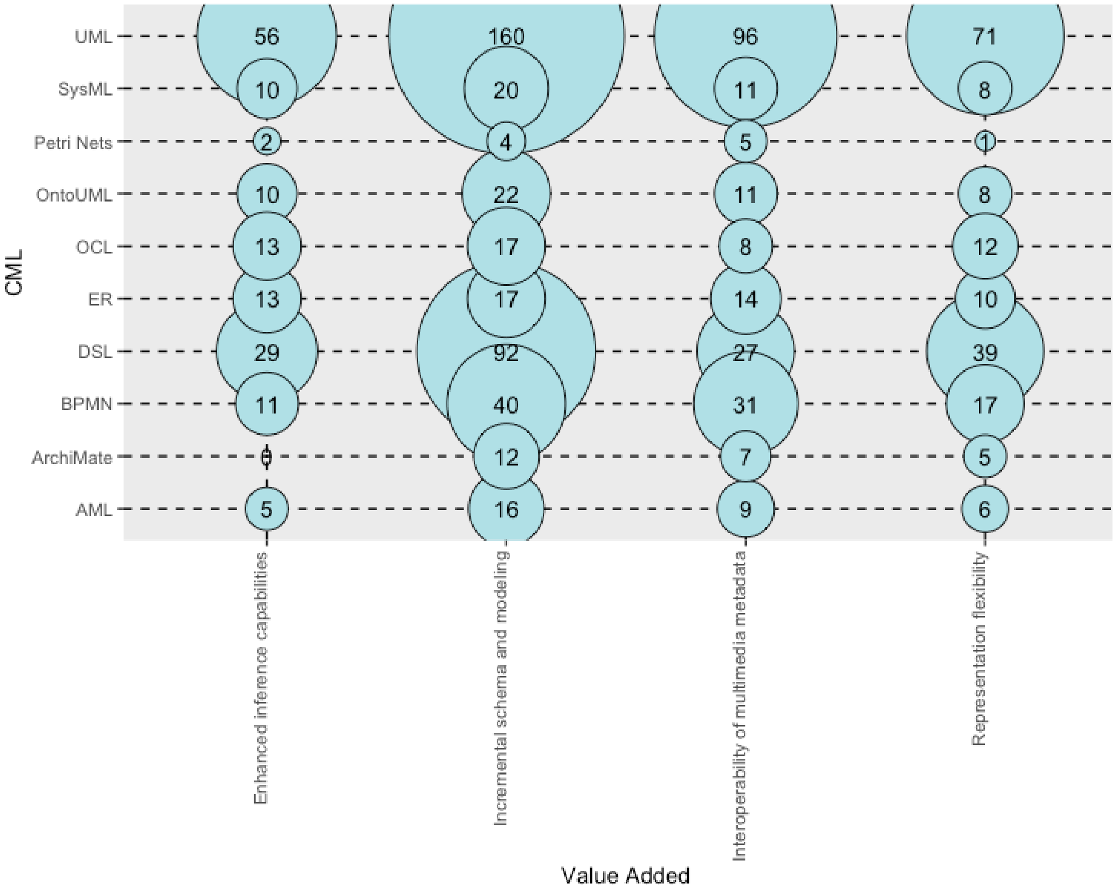

Figure 6.25: Nr. of publications by value added and CML

representation and *analysis* prevailed across the activity areas. The largest part was in both analyzed time periods the category of *foundational* papers. The modeling purposes *representation* and *code generation* have become more extensive in combination with the activity areas *IT*, *manufacturing*, *healthcare*, and *education* over time. The *cultural* and *education* activity area stayed very small with regard to *representation*, *code generation*, and *analysis* as modeling purposes. The publications in the *tourism* activity area has grown stronger in combination with the modeling purpose *representation*, and *government* the other around. In addition to this, the *legal* activity area performed a shift from *code generation* to *representation* and *analysis* at a low level.

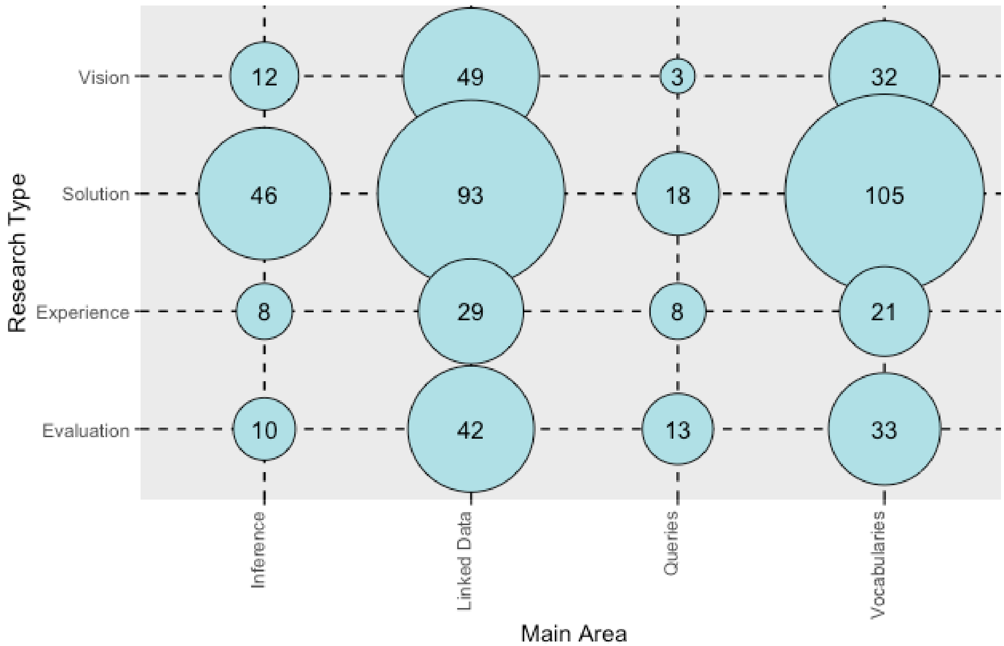

Figure 6.26: Nr. of publications by W3C main area and research type

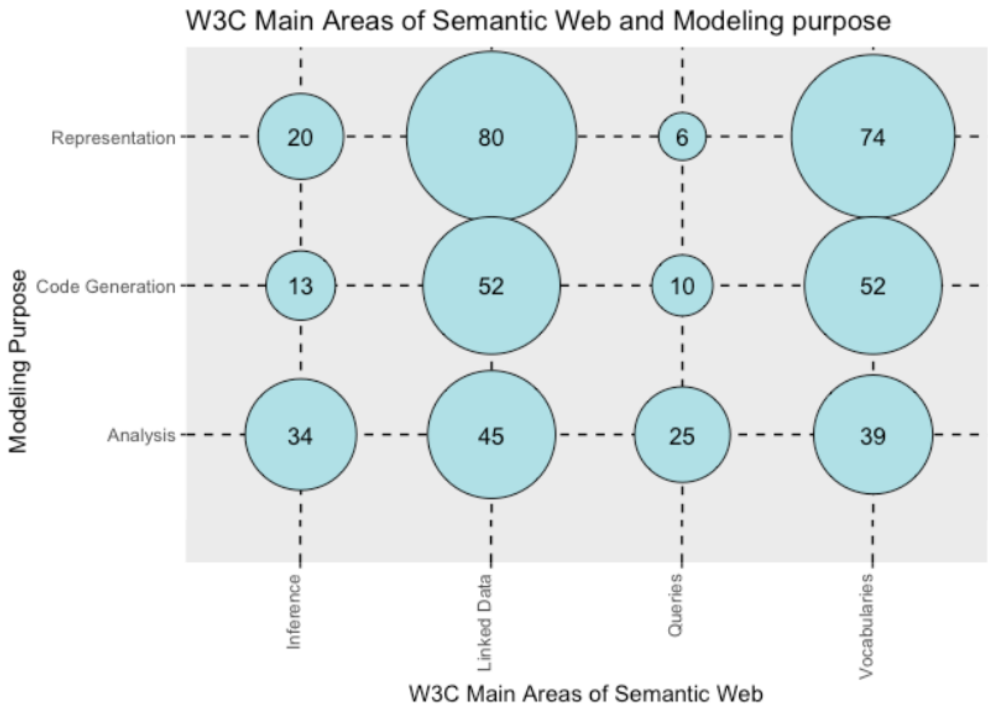

Figure 6.27: Nr. of publications by value added and modeling purpose

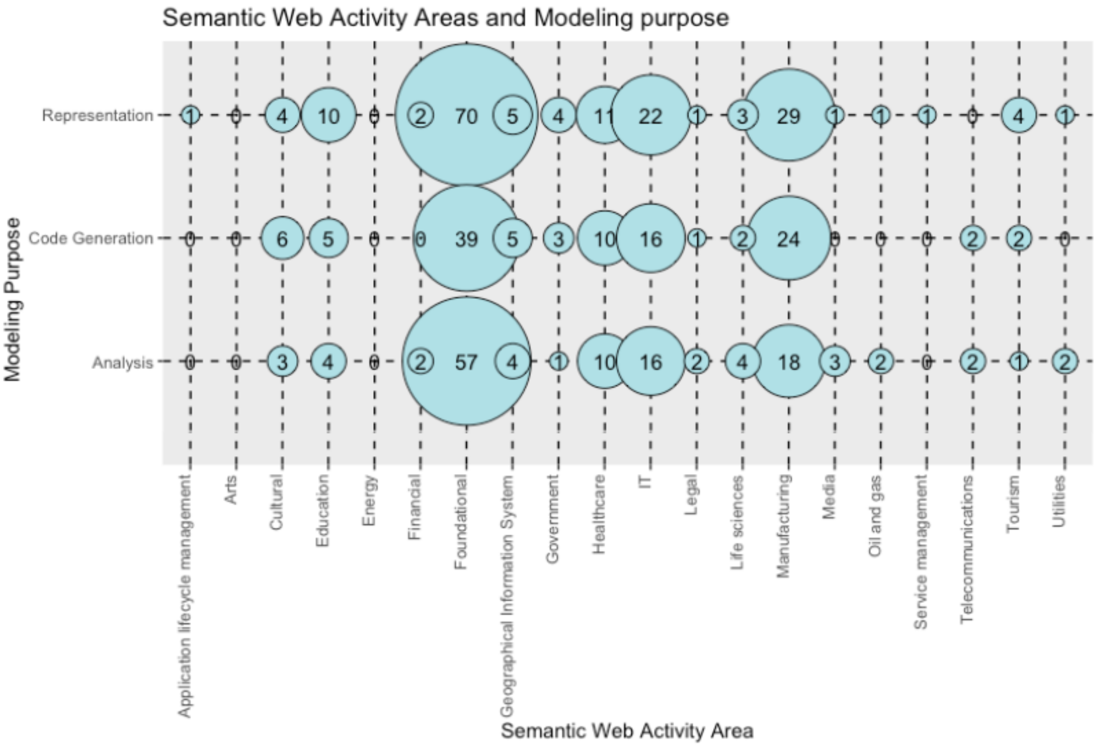

Figure 6.28: Nr. of publications by activity area and modeling purpose

6.5 Research Community Analysis

In line with the research community analysis, the relationships between researchers at the intersection of conceptual modeling and Semantic Web topics were explored in the form of knowledge graphs, and their main topics were identified.

Figure 6.29 depicts the whole publication landscape used for this systematic mapping study in the form of a co-authorship graph weighted by documents. The main research communities are highlighted in color and are shown in bigger font size according to their document output weighting (see Figure 6.29). According to Figure 6.29, some of the largest research clusters are structured around the researchers M. Wimmer, R. Verborgh, T. Walter, D. Gasevic, M. Malki, G. Guizzardi, R. A. Buchmann, J. Sun, G. Kardas, H. Paulheim, X. Zheng, and X. Wang.

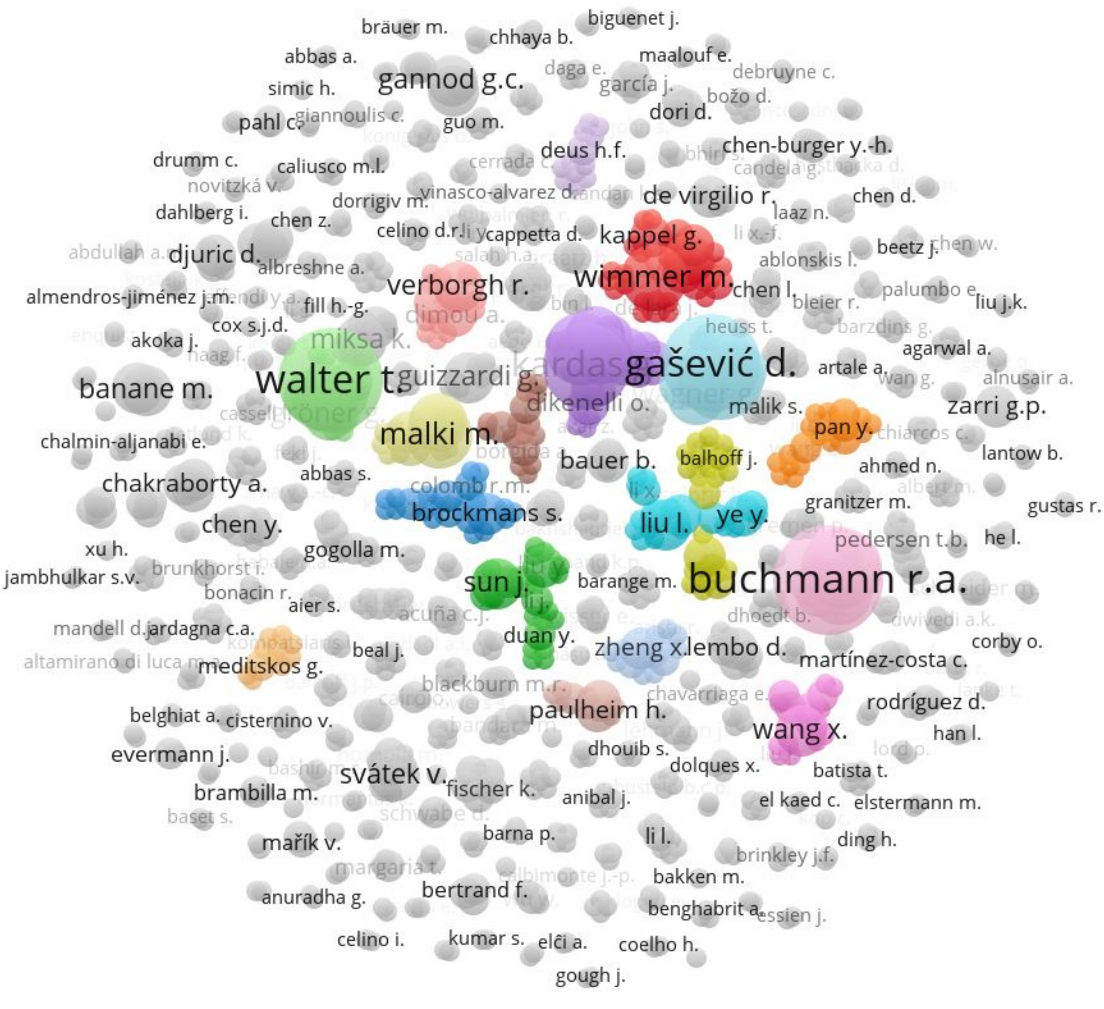

Figure 6.29: Co-authorship graph weighted by documents

From the overall knowledge graph, one can go into further detail to extract information on the individual research communities. In Figure 6.30, the research communities around M. Wimmer, G. Kardas, and D. Gasevic are presented in greater detail.

Manuel Wimmer, whose community is depicted in red in Figure 6.30, is currently a professor at the Johannes Kepler University Linz (Austria), but was at the time of his publications listed in this SMS employed at the Vienna University of Technology (Austria). Some of the researchers and professors co-authoring papers with him are for instance G. Kappel, E. Kapsammer, W. Schwinger, W. Retschitzegger, J. Delara, M. Sabou, S. Biffl, F. Ekaputra, and O. Kovalenko, many of whom were colleagues from the Vienna University of Technology (Austria) or Johannes Kepler University Linz (Austria). The most prevalent topics into which Manuel Wimmer has been involved were model transformation, automation in software engineering, graph grammars, UML, with a focus on an industrial context.

Geylani Kardas's community is depicted in violet in Figure 6.30, and is linked to M. Challenger, S. Getir, T. Kosar, M. Mernik, and A. Goknil, amongst others, who are mainly working in research at Ege University (Turkey). The main topics covered by this research community evolve around agent-oriented software engineering, multi-agent systems, and domain-specific modeling.

The third cluster in Figure 6.30 is highlighted in light blue and is structured around *Dragan Gasevic* from Monash University (Australia) and includes V. Devedzic, G. Wagner, A. Giurca, and H. S. Carvalho. Gasevic's community devotes to self-regulated learning and modeling in an educational context.

Figure 6.31 comprises firstly the research group of *Tobias Walter* (highlighted in green) who is currently a professor at the University of Stuttgart (Germany), and was at the time of the publications used for this SMS employed by the University of Koblenz-Landau (Germany). His research community includes F. S. Parreiras, G. Gröner, F. Silva Parreiras, T. Franz, and J. Ebert, most of whom were either researchers from the University of Koblenz-Landau (Germany) or from Universidade FUMEC (Brazil). The publication topics of this research cluster are focused around model-driven software engineering, logic, and formal languages which can be used for inference.

The second research community shown in Figure 6.31 is the one around Mimoun Malki (colored in yellow) who is currently a professor at École Supérieure en Informatique Sidi Bel Abbes (Algeria), and was at the time of publication employed by Université Djillali Liabes de Sidi Bel Abbes (Algeria). The research community has links to D. Bensaber, D. Bouchiha, B. Bouougada, who were all research colleagues from the same university in Algeria, amongst others. The research community around M. Malki concentrates on topics like ontology alignment, schema matching, Semantic Web related aspects, and multi-dimensional modeling.

Giancarlo Guizzardi is at the center of the third research community shown in Figure 6.31, and is a professor at the Free University of Bozen-Bolzano (Italy). He previously conducted research at the Federal University of Espirito Santo (Brazil). His research

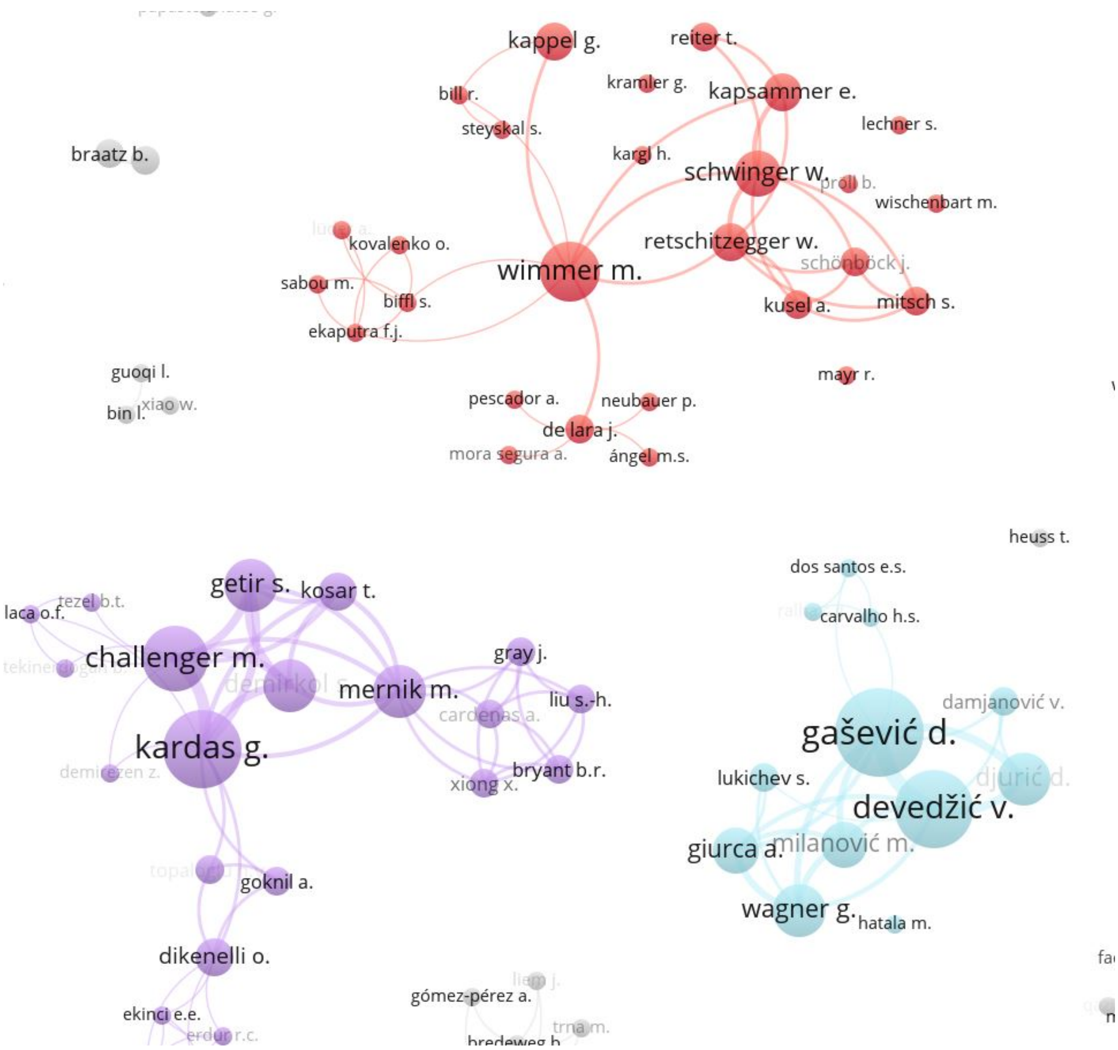

Figure 6.30: Co-authorship graph: clusters Wimmer, Kardas, Gasevic

community expands mainly across those two universities, and comprises for example J. P. Almeida, V. Carvalho, M. Dudas, T. P. Sales, and V. Svatek. The topics covered range from conceptual modeling languages to ontologies, ontology-based modeling, knowledge graphs as well as their underlying grammars, model transformation, and logic reasoning.

The fourth research community is centered around *John Mylopoulos* who is currently a researcher at the University of Ottawa (Canada), and previously completed his publications at the University of Toronto (Canada). His community includes S. Khan, S. Liaskos, D. Plexousakis, P. Constantopoulos, A. Borgida, and M. Doerr who served for example for the University of Regina and York University. Business process modeling, conceptual modeling languages, and ontologies are among the most prevalent topics in this community.

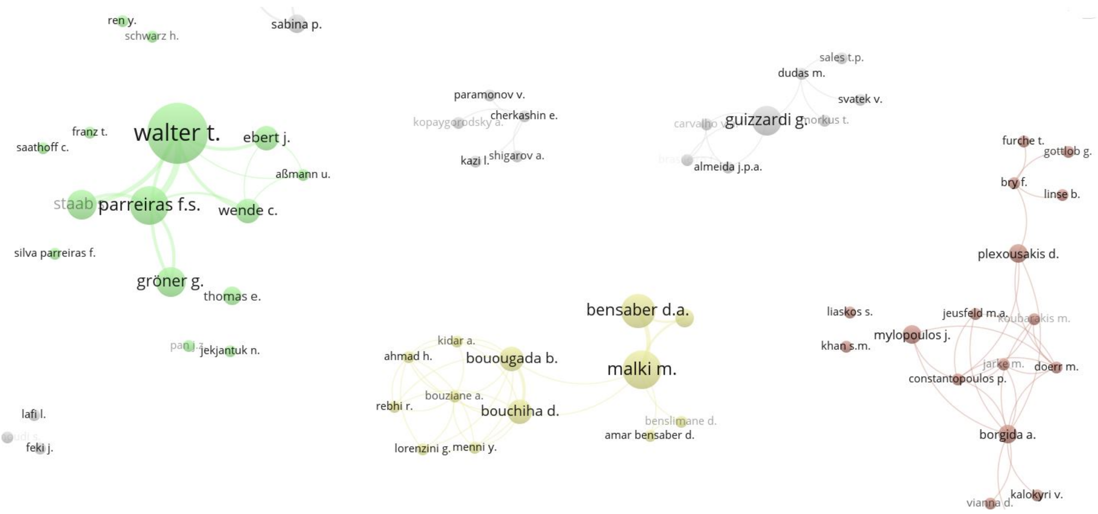

Figure 6.31: Co-authorship graph: communities Walter, Malki, Guizzardi, Mylopoulos

The research community depicted in Figure 6.32 is centered around *Robert Andrei Buchmann* who has been a researcher at the University Babes-Bolyai (Romania). The community extends to D. Karagiannis, A.-M. Ghiran, A. Harkai, M. Walch, A. Chis-Ratiu, and M. Cinpoeru who are researchers from the University of Vienna (Austria) and the University Babes-Bolyai. The research focus of this community is placed on enterprise modeling, business process modeling, and semantic modeling.

Figure 6.32: Co-authorship graph: cluster Buchmann

Figure 6.33 illustrated the co-authorship graph from another angle, namely weighted by citations. Compared to Figure 6.29 which used a document weighting, the weighting by citations emphasized other clusters. In both weighting scenarios for example H. Paulheim and D. Gasevic were mentioned. But in the citation-weighted knowledge graph, as depicted by Figure 6.33, the clusters around H. F. Deus, E. Palumbo, C. Martinez-Costa, D. J. Mandell, G. Guizzardi, S. Brockmans, and H. Solbrig gained in size, and were therefore the most cited ones.

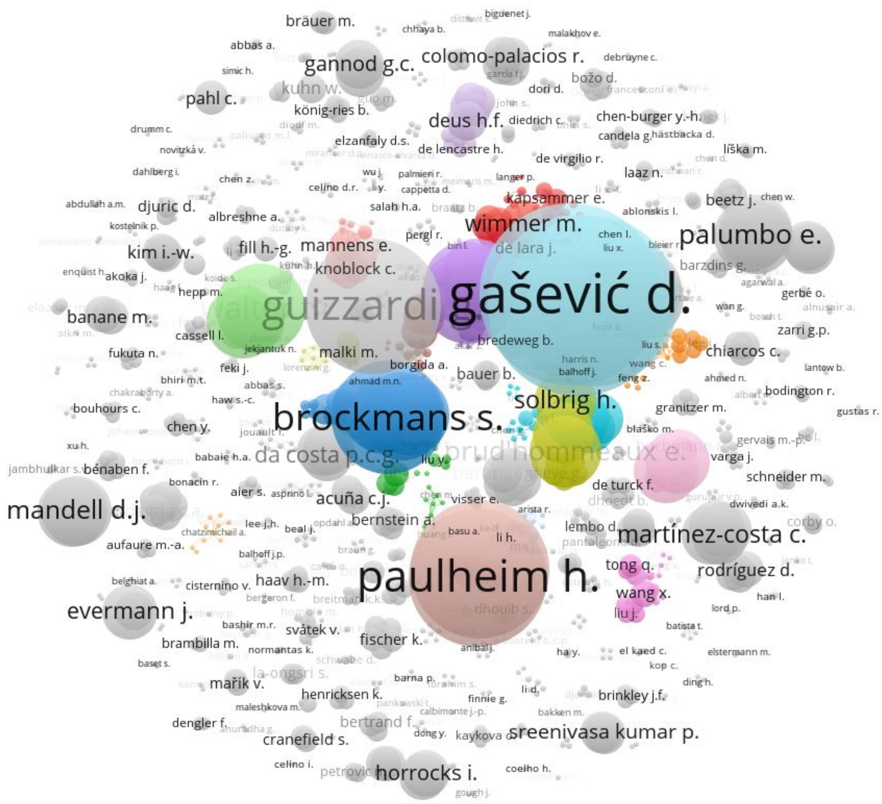

Figure 6.33: Co-authorship graph weighted by citations

Figure 6.34 adds the time component to the co-authorship graph with document-based weighting. As already mentioned, the chosen publications range from the year 2005 to 2022. The earlier years, i.e. around 2005, are colored in dark blue, and the lighter the colors get, the further time progress is visualized, until the year 2022 is reached in the form of the yellow color, as Figure 6.34 illustrates. Thus, for example the research communities around D. Gasevic, S. Brockmans, L. Liu, and D. J. Mandell (all colored in dark blue) were very early publications in the analyzed research area, whereas the research clusters around C. Cerrada, M. Banane, H. Ding, or A. Borgida have recently published their papers.

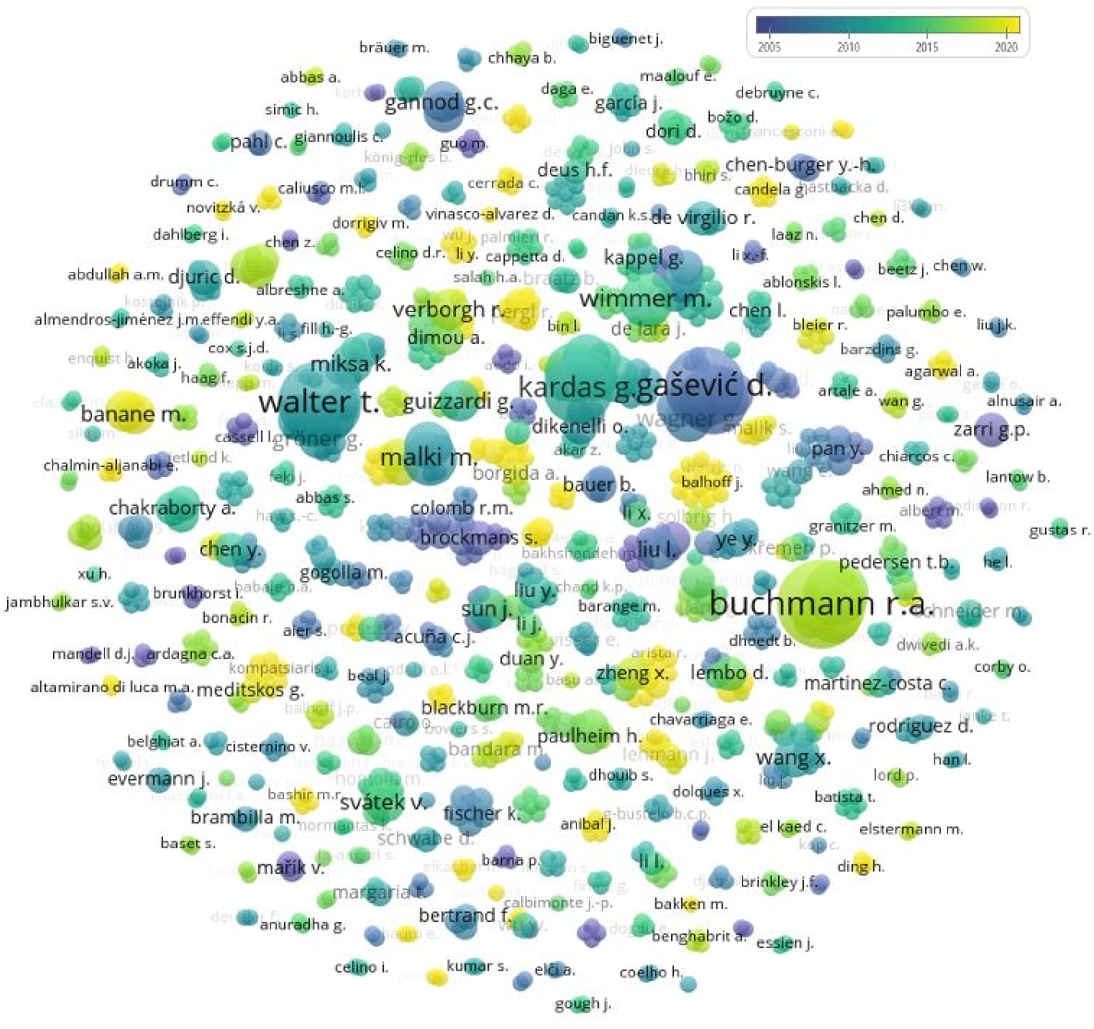

Figure 6.34: Co-authorship graph weighted by documents

The number of citations is again considered in Figure 6.35, which shows the publications with fewer citations in dark blue, and reaches on the color palette up to yellow, which indicates the highest number of citations obtained by a publication. So, based on Figure 6.35, it can be seen that the research communities with the highest number of citations are centered around D. Gasevic, J. Garcia, H. F. Deus, S. Brockmans, H. Paulheim, S. Kumar, M. Wimmer, to name a few.

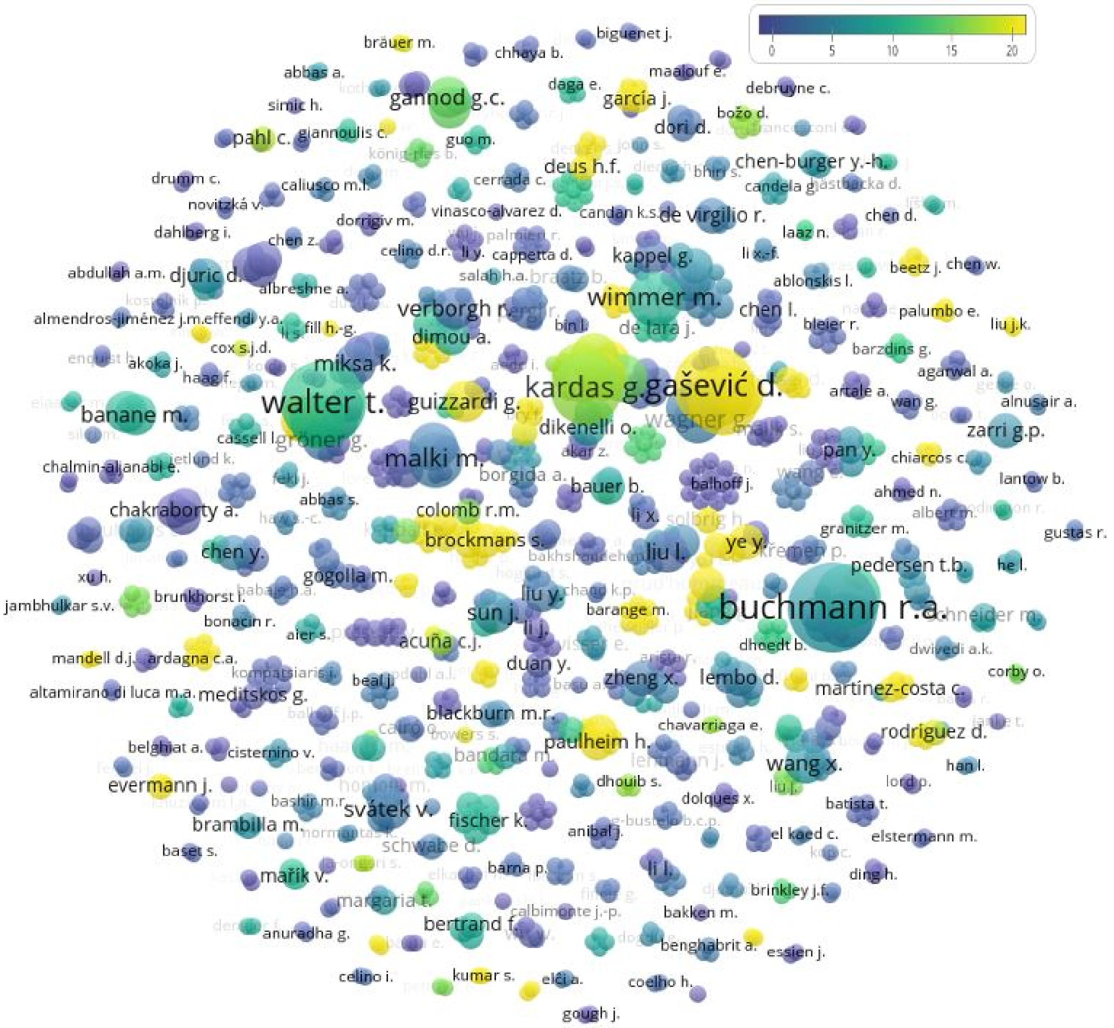

Figure 6.35: Co-authorship graph weighted by citations

The Figure 6.36 deals again with the main research communities, for which the cluster density is shown. It indicates that the main cluster are structured around T. Walter, S. Brockmans, Y. Liu / J. Sun, L. Liu, D. Gasevic, G. Kardas, M. Wimmer, and R. A. Buchmann.

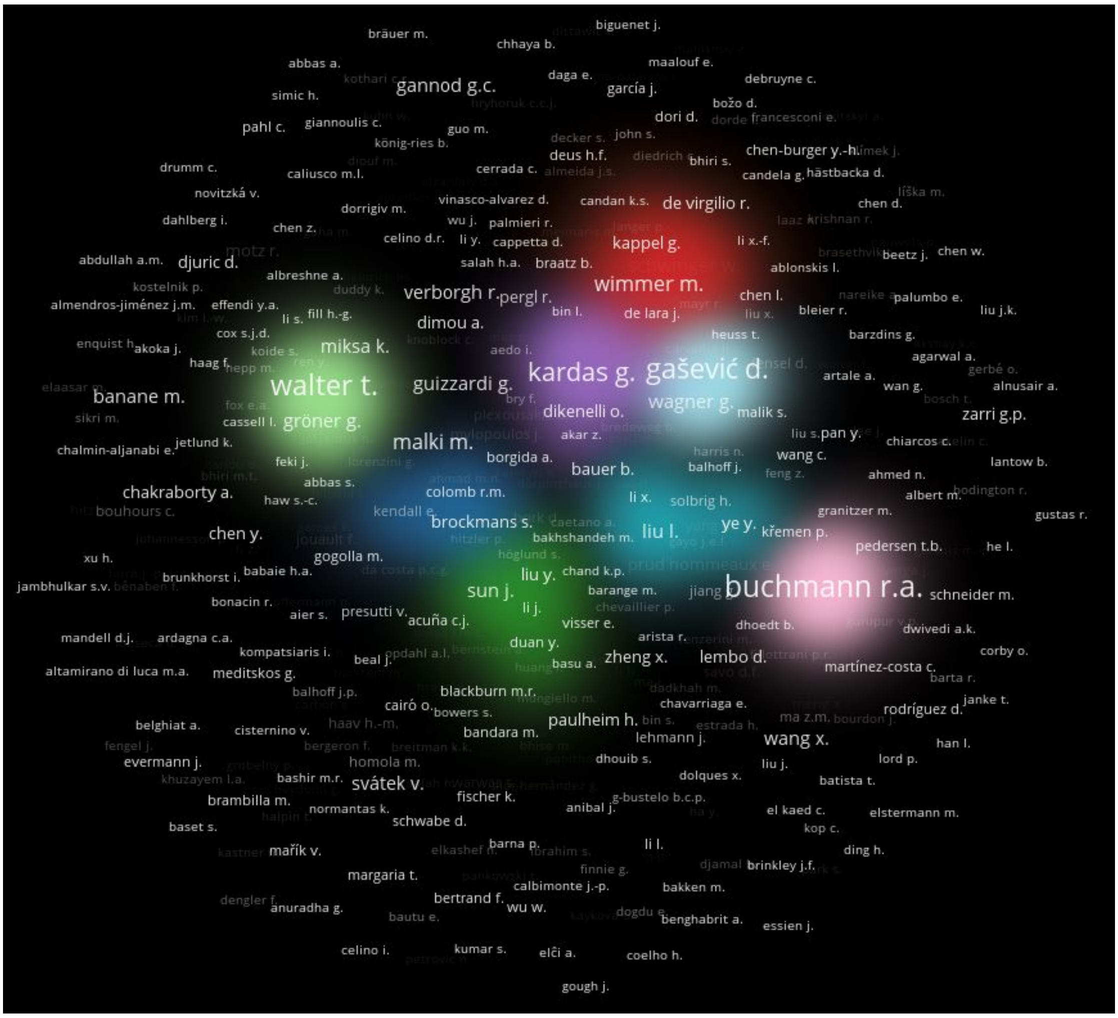

Figure 6.36: Research cluster density

In line with Figure 6.37, the organizations of the authors that published research work at the intersection of conceptual modeling and Semantic Web are depicted in the form of a knowledge graph. The knowledge graph is weighted by documents, i.e. publications in the field of research under concern. This means that the higher the document weighting, the larger the respective institution is represented. Furthermore, the most prevalent institutions obtained a specific color highlighting. For example Ege University (Turkey), University of Koblenz-Landau (Germany), University of Karlsruhe (Germany), University of Belgrade (Serbia), Maharastra Institute of Technology (India), Vienna University of Technology (Austria), University of Vienna (Austria), BOC Information Systems GmbH (Austria), Massachusetts Institute of Technology (USA), Stanford University (USA), Mayo Clinic (USA), Northeastern University (USA), and University Babes-Bolyai (Romania) were among the most contributing institutions, when considering a weighting by documents.

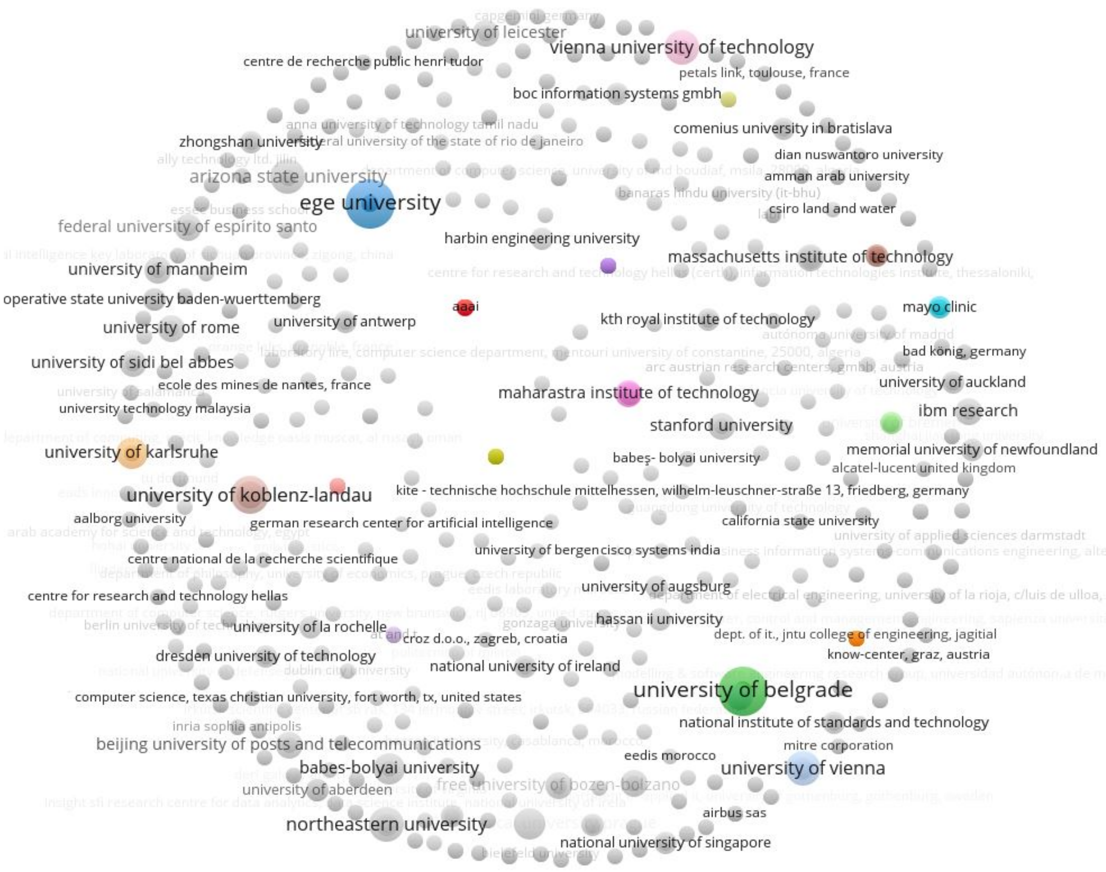

Figure 6.37: University graph weighted by documents

The document weighting is expanded by time in Figure 6.38, which shows what kinds of institutions published earlier pieces of research work, and which ones published them later. For instance the University of Karlsruhe (Germany), National University of Singapore (Singapore), and Stanford University (USA) published early research around the year 2005. Among the universities that published mostly in the 2010s are the Vienna University of Technology (Austria), University of Mannheim (Germany), Ege University (Turkey), IBM Research (global), and Northeastern University (USA). Later publications towards 2020 were made for instance by KTH Royal Institute of Technology (Sweden), Technische Hochschule Mittelhessen (Germany), Texas Christian University (USA), and University of Antwerp (Netherlands).

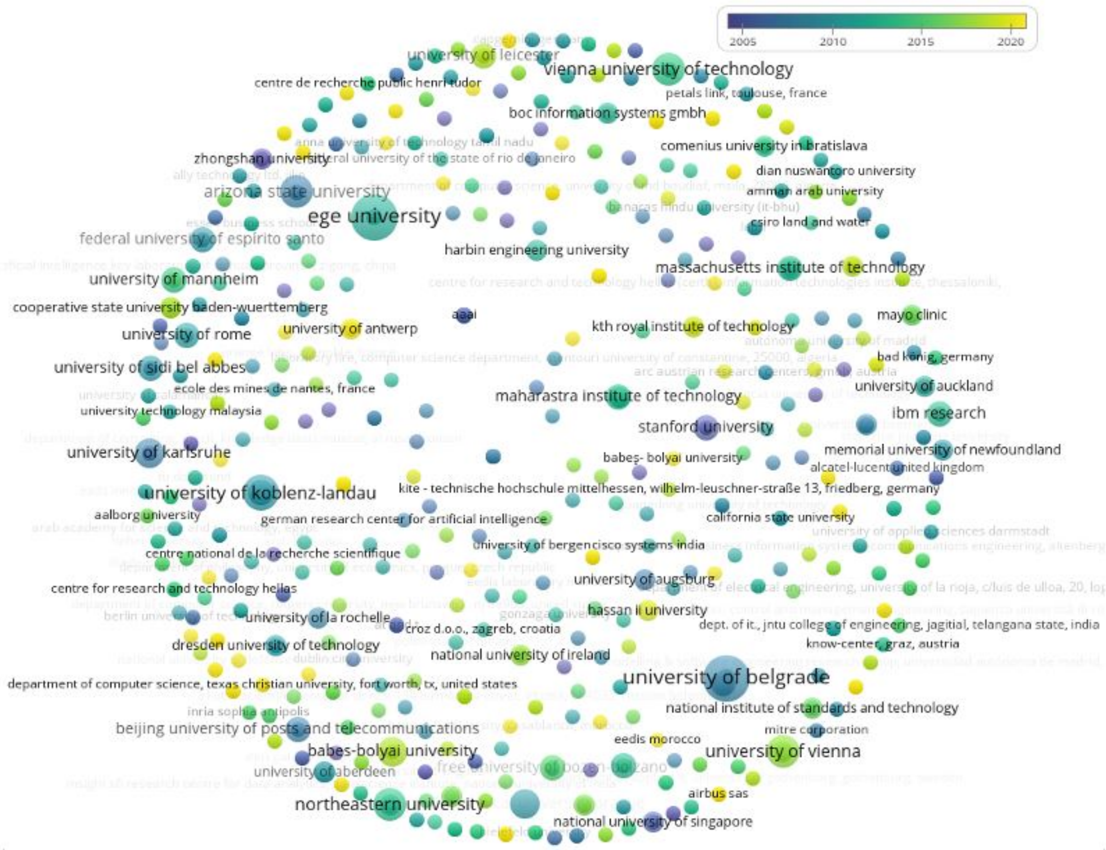

Figure 6.38: University graph weighted by documents incl. time

The weighting by citations in line with the institutional view and in combination with the time component (in the range from the year 2005 to 2022) is shown in Figure 6.39. This knowledge graph illustrates that very early papers with a considerable number of citations were published by Zhongshan University (China), Stanford University (USA), Deri Galway (Austria), Alcatel-Lucent (United Kingdom), University of Belgrade (Serbia), Dublin City University (Ireland), and University of Karlsruhe (Germany) (see Figure 6.39). Among the publishing institutions around 2010 to 2015 with a high number of citations were the Federal University of Espirito Santo (Brazil), University of Mannheim (Germany), Ghent University (Belgium), Northeastern University (USA), and Institute for Web Science and Technology Koblenz (Germany), as Figure 6.39 illustrates. At the later end of the time scale for instance Eurecom Sophia Antipolis (France), Beijing Institute of Technology (China), and Hassan II University Casablanca (Morocco) published research work which can be seen from Figure 6.39.

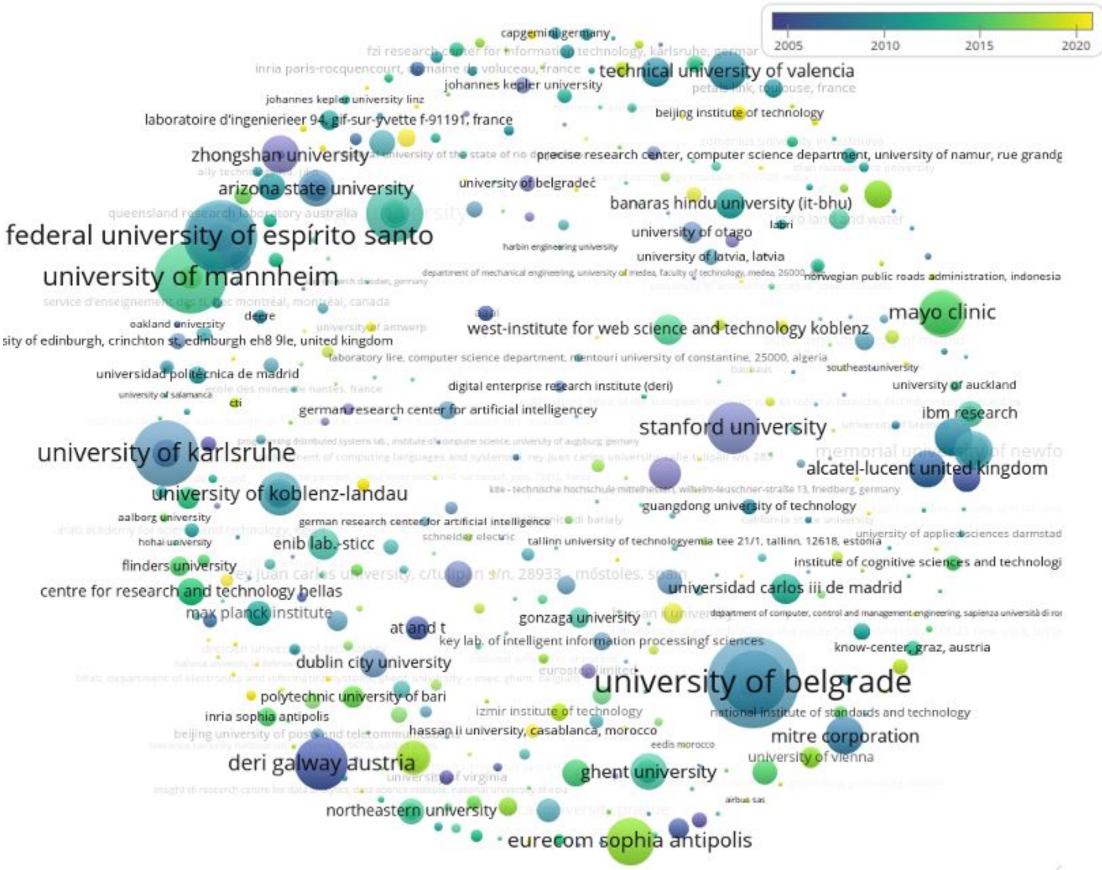

Figure 6.39: University graph weighted by citations

Figure 6.40 finally illustrates an excerpt of the knowledge graph as a network between the top publishing countries, weighted by documents (i.e. publications). According to Figure 6.40, Germany, the United States, China and France are weighted most heavily in terms of the number of publications, and all share extensive links to other countries. Germany is in this network tightly linked to the United States, the United Kingdom, France, Canada, and Romania, including Serbia via Canada. The United States are apart from this linked tightly with China, Australia, and somewhat with Turkey. France is related closely with Italy, Algeria, Switzerland, and Spain, including Austria via Spain.

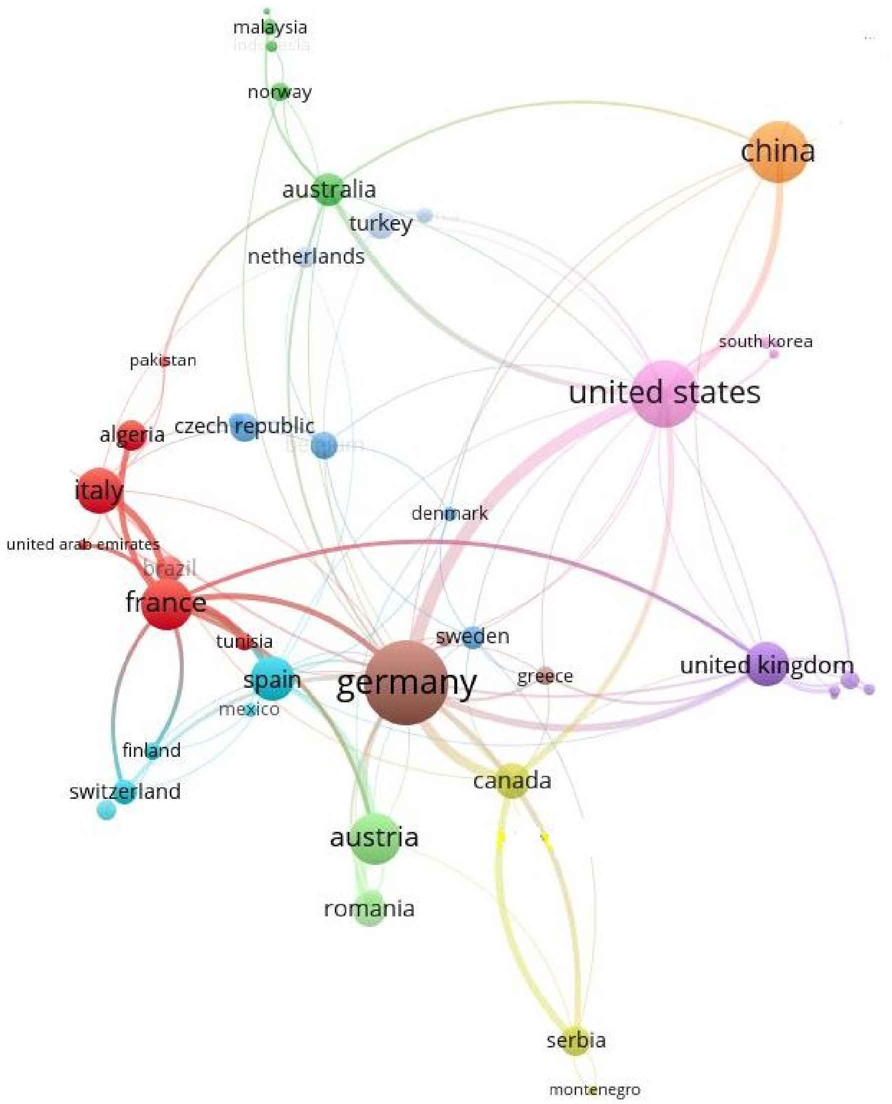

Figure 6.40: Top publishing countries weighted by documents

CHAPTER 7

Web Knowledge Base

The web knowledge base aims to provide self-service functionalities to explore the data of the systematic mapping study. Functionalities comprise the detailed analysis results with regard to the countries and modeling languages as well as concerning the taxonomies. Moreover, it offers search opportunities so that publications can be retrieved according to search terms and taxonomies. The web knowledge base is accessible via `http://me.big.tuwien.ac.at/cmsw`.

Figure 7.1 shows the login page of the web knowledge base, for which the user name and the password need to be entered to complete the sign-in process.

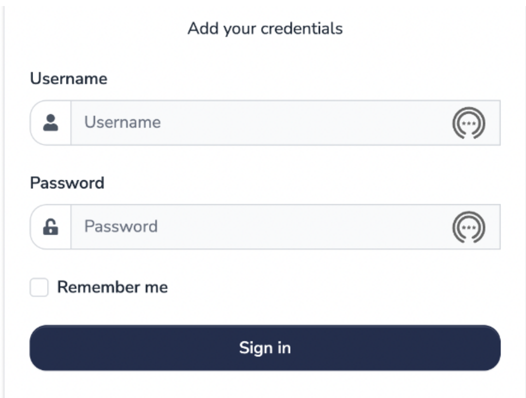

Figure 7.1: Login page

Figure 7.2 shows the landing page at which the user arrives after the login process. This page offers the opportunity to enter a search key word for which a list of publications that contain the search term are retrieved from the web knowledge base. The search term refers either to publications, venues, or authors. On the lower side of the page, frequency tables concerning the *country by authors*, *country by papers*, *institute by papers*, *institute by authors*, *modeling languages by publications*, and *author by papers* can be displayed based on the systematic mapping study data.

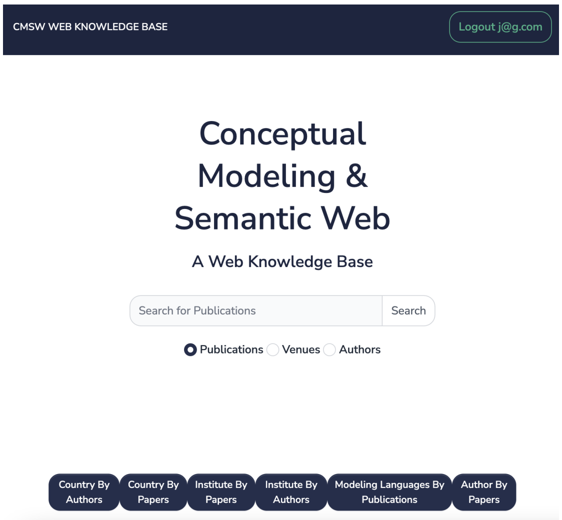

Figure 7.2: Main page

For instance the *detailed analysis of author by papers* is illustrated in Figure 7.3, which represents the name of the authors on the left side, and the number of papers published by those authors in the right column.

Figure 7.3: Details: Author by Papers

The results of an exemplary search for the search term *UML* are displayed in Figure 7.4. In this case, 95 results, i.e. publications, were found in the web knowledge base. The title, the publication year, the authors, the abstract, and the badges (meaning the taxonomy elements assigned to the respective publications) are shown in the resulting columns. By clicking the button in the abstract column, the abstract of the selected publication can be displayed.

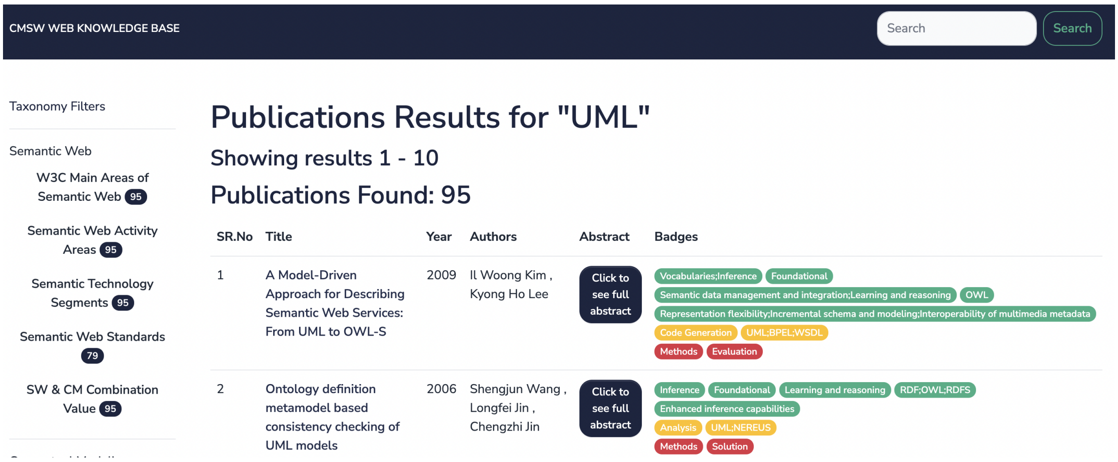

Figure 7.4: Search

The menu on the left side also provides the *taxonomy filters*, by which some taxonomy elements can be selected or unselected as the user prefers. By clicking the button *Apply Filters*, the selection can be confirmed and the publication results are displayed according to the filters set, whose selection is shown in Figure 7.5.

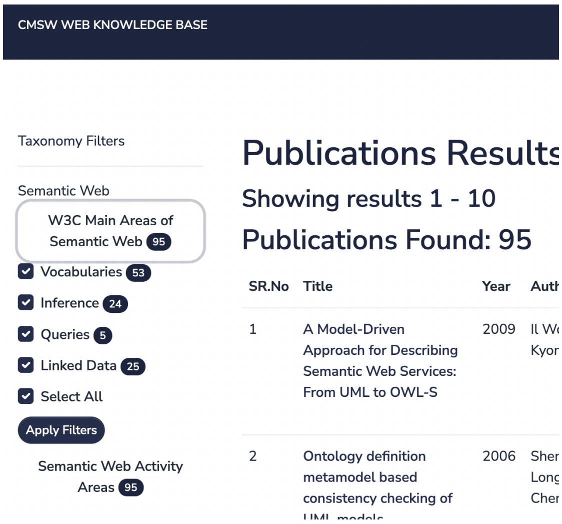

Figure 7.5: Taxonomy filters

CHAPTER 8

Threats to Validity

The term "*validity*" refers to degree of reliability and correctness of the results of the systematic mapping study [13] [64]. Hence, in this chapter potential limitations, i.e. "threats to validity", of the SMS are reviewed from a critical perspective. According to De Souza Neto (2018), validity can be categorized into several sub-types, namely "conclusion validity, internal validity, construct validity, and external validity" which will be reviewed in this chapter respectively [13].

As for *conclusion validity*, this type of validity deals with the "relation of the research process to the outcomes" [13] and its replicability by the means of using an appropriate systematic research method [**?**]. A potential threat in this category is presented by how the search for papers was conducted in this thesis, as the selection of specific inclusion criteria (IC1-IC5) or exclusion criteria (EC1-EC6) might have had a considerable impact on the number of papers as well as on the content of papers that finally remained in the list of publications subject to analysis. The screening phase also involved only title and abstract of the publications, and no further attributes. These criteria referred for example to the language, research area, length, and year of publications, which could have led to a diverging conclusion in case different choices had been made. In addition to this, the systematic mapping study was based on literature search runs in the publication databases ACM Digital Library, Web of Science, Scopus, and IEEE Xplore, which is only a selection of the publication databases available, and might thus limit the generalizability of the conclusion. Precautions to ensure conclusion validity was the systematic execution of the methodologically given phases for the SMS, with the goal to draw conclusions only once the method allows for it.

Secondly, the *internal validity* refers to the fact that there might be "a relationship between the treatment and the outcomes" [13], or as Wortmann (2017) specified it to the "extraction of information" from the underlying data [64]. Threats to this type of validity might have occurred in the process of evaluating the publications as relevant or non-relevant, and in the process of assigning taxonomy elements to the papers based on the abstracts and / or full text. At this point, it might have happened that relevant papers were overlooked or non-relevant papers have inadvertently been added to the final list of selected publications. Moreover, taxonomy elements might have been incorrectly or contradictorily assigned to the publications (e.g. due to skipped information or poor analysis of the content) so that the internal validity or correctness could have been hampered.

As a third type, *construct validity*, which refers to "the relationship between the theory and the observations, while reflecting the researcher's initial expectations" according to De Souza Neto (2018), could have been negatively impacted [13]. According to Wortmann (2017), construct validity is affected by the research design and the formulation of adequate research questions [64]. With regard to construct validity, the search queries were compiled using previous related research as a yardstick, but it could have happened that relevant terms or synonyms might have been left out, and therefore led to papers not being included in the SMS. Some of the search query components might have been too specific or too general. Relevant combinations of terms might also have been overlooked in the search string definition process so that the RQ might not be fully answered. To prevent this threat from happening, the selection process of the publications, and classification as relevant or not based on abstract and title was carried out once and then reviewed in a second correction run. Likewise, the classification according to the taxonomies was carried out and reviewed to spot misclassifications and contradictory data entries. Furthermore, the search query was adapted and tested with different search terms in order to find out about terms that could largely impact the number of publications in the search result.

Threats to *external validity* finally refer to issues regarding the "generalizability of the results outside the scope of the study" [13]. The systematic mapping study might be limited in generalizability as not all relevant papers might have been captured in the selection process, and / or not sufficient or sufficiently targeted previous related work (at the intersection of conceptual modeling and Semantic Web) might have been analyzed upfront as a basis for the this SMS. The selected papers were also selected from a time period from 2005 up to May 2022, which means that after that limit further critically relevant papers might have been published outside the chosen time frame, and are now missing in this study. Another external validity problem might be the fact that some rare case happened in which papers that looked relevant were unavailable, and therefore had to be excluded from the analysis, which means that their contribution to the research field is now missing. However, this SMS covers a very specific topic so that threats to generalizability are as such of lesser importance compared to the other threats to validity, as the SMS aims to be representative for its narrow research topic at the intersection of conceptual modeling and Semantic Web.

CHAPTER 9

Implications for Future Research

The research questions formulated in the chapter 4 were answered in line with the analysis phase of this systematic mapping study. They dealt with diverse facets of the research area under concern such as the evolution of the research area at the intersection of conceptual modeling and semantic web evolved over time in general, and with regard to publication, research, contribution type, as well as modeling purpose, with the main contributing institutions, countries as well as publication channels. In addition to this, the main research communities were analyzed in the form of knowledge graphs, and their research focus in terms of covered topics was determined. The publications were analyzed with regard to the different laid out taxonomies as well as combinations thereof.

The findings showed that the number of publications has been growing annually over the last decades, and that the topics at the intersection of conceptual modeling and Semantic Web have become more and more interlinked. This could also be observed by a sharper increase in journal articles more recently compared to conference proceedings, which could hint towards a beginning process of maturation. However, this is so far just a presumption, but should be analyzed in future research to identify where this field of research heads to.

As no other systematic mapping study exists on this same topic, this thesis elaborated as the first taxonomies based on previous research output from somewhat overlapping topics. Given this fact, future research still needs to verify how appropriate the selected taxonomies are, as no yardstick had existed at the time of writing of this SMS. In addition to the taxonomy topics in general, their taxonomy elements should also be critically examined with regard to completeness and relevance. Based on this, future research should try to replicate the results achieved with this piece of research as well in order to verify the quality of the conclusion. One more suggestion for further research is the time range examined, which was limited to publications from 2005 to May 2022. In the future, it would be recommended to open up the time range to cover the field of research at an even wider scale.

When it comes to the findings, it turned out that the most frequently occurring research type was the *solution* paper, while the types *vision*, *experience*, and *evaluation* were not as prevalent. The same tendency holds for the contribution type, for which *concepts* and *methods* prevailed, and *tools*, *algorithms*, and *discussions* were rather rare. As for conceptual modeling languages, UML, DSL, and BPMN were most frequently occurring, but others like SWRL, OntoUML, SysML, ER have been on the rise. Given the above insights, future research should firstly watch the further development of those tendencies, and should secondly focus on inspecting why those differences exist, what factors contribute to this situation, and more closely examine the papers of the rare types.

As already mentioned, this systematic mapping study covered a topic that was previously not covered at all by research. The taxonomies are a first suggestion, but their suitability still needs to be evaluated. Future research should therefore review them critically, and also think about adding further taxonomies such as for ontologies or ontology languages, notably at the intersection of CM and SW.

With respect to the W3C main areas, *linked data* and *vocabularies* were covered a lot, but *inference* and *queries* not so much. The same situation was observed for the taxonomy referring to the value added of CM and SW, which led to *incremental schema and modeling* as the mainly appearing category, followed by *interoperability*. Such discrepancies could constitute an interesting topic for future research as well. Furthermore, among the Semantic Web standards OWL, RDF, and SPARQL were most prevalent, followed by the category "*no match*", which would again require future research to determine why there was no match, and what kinds of publications are affected by this. Concerning the difference between *foundational* and *industry-specific* Semantic Web activity areas, future research should analyze them separately as well to find out about respective particularities.

In line with this SMS, a series of combinations of two taxonomies were analyzed in both a quantitative and a visual way (see e.g. Figure 6.20 or 6.20). They were extended by a third dimension, namely the time component. Still, future research should aim to combine more taxonomies in order to generate even more fine-grained insights into the publications data.

The SMS finally gave an overview on the main research communities including their most contributed topics. In relation to this, future research should cover the links within as well as between research clusters in even greater depth to capture relationships that have previously not been revealed, and to reveal the full dynamics of research communities.

CHAPTER 10

Conclusion

This thesis explored the research landscape at the intersection of conceptual modeling and the Semantic Web in the form of a systematic mapping study that comprised 484 publications. It followed the research method guidance regarding SMS from Petersen (2008) [42] and Kitchenham (2011) [28] which comprised the phases to *define the research scope*, *conduct the search*, *screen the publications*, *keyword the abstracts*, and *extract and map the data*. In line with the systematic mapping studies, the seven research questions formulated in chapter 4 were answered using the classification scheme, i.e. the taxonomies developed in the keywording phase of the SMS.

The first research question (**RQ1**) aimed to explain how the research area at the intersection of conceptual modeling and semantic web evolved over time in general, and with regard to publication, research, contribution type, as well as modeling purpose. The data analysis indicated that the research area under concern has been subject to substantial growth since 2005. More precisely, the number of publications increased from around three to five annually (in the late 2000s) to almost 60 annually (around 2020). In terms of publication types, there has been a shift from conference proceedings to journal articles which hinted towards a beginning maturing process in the research area. Among the various research types, the *solution* type has prevailed over the observed time period, followed by the *evaluation* type, although it can be said that all research types including *vision* and *experience* have increased in publications until 2022. As for the contribution types, *methods* papers have surged since 2015, and *concepts* papers have started to catch up in 2019. *Discussions*, *tools*, and *algorithms* rather declined in publication activity. Concerning the modeling purpose, most publications aimed to *represent* or *analyze*, but *code generation* was not tremendously lagged behind, but just stayed stable at a lower level.

The second research question (**RQ2**) intended to identify the main contributing institutions, in what publication media did they publish their research, and in which countries were those institutions located. Based on the number of researchers, the Federal University of Espirito Santo (Brazil), the Kaunas University of Technology (Lithuania) and the Free University of Bozen-Bolzano (Italy) ranked at the top of publishing institutions in this research field. Based on the number of publications (when counting the institution only once), the Federal University of Espirito Santo (Brazil), the University of Vienna (Austria), and the Free University of Bozen-Bolzano (Italy) achieved the top spots in the ranking from 2005 to May 2022. Among the top journals were the Journal of Biomedical Informatics, Expert Systems with Applications, and IEEE Transactions on Services Computing. Among conferences, the most frequently occurring ones were Conceptual Modeling (ER), IEEE International Conference on Engineering Technologies and Factory Automation, and Winter Simulation Conference.

The third research question (**RQ3**) aimed to explore the main contributing researchers and research communities in the field, what topics they are focusing on, and how do these research groups interact. As main contributing research communities, the analysis identified the clusters around T. Walter (University of Koblenz-Landau / Germany), M. Malki (Université Djillali Liabes de Sidi Bel Abbes / Algeria), M. Wimmer (Vienna University of Technology / Austria), R.A. Buchmann (University Babes-Bolyai / Romania), H. Paulheim (University of Mannheim), G. Meditskos (Aristotle University of Thessaloniki / Greece), R. Verborgh (University of Ghent), G. Guizzardi (Free University of Bozen-Bolzano / Italy and Federal University of Espirito Santo / Brazil), S. Brockmans (Karlsruhe Institute of Technology / Germany), D. Gasevic (Monash University / Australia), and G. Kardas (Ege University / Turkey)[1]. The cluster of M. Wimmer focuses on model transformation, model-driven engineering, knowledge graphs, and UML. The main topics covered by the research community around Kardas evolve around agent-oriented software engineering and multi-agent systems combined with domain-specific modeling languages. Gasevic's community devotes to modeling in an educational context. The publication topics of the research cluster around Walter are focused around model-driven software engineering, logic, and formal languages. The research community around Malki deals with topics like ontology alignment, schema matching, and multi-dimensional semantic modeling. The research focus of R. Buchmann's community is placed on enterprise, business modeling, and semantic modeling.

The fourth research question (**RQ4**) tried to find out whether the contributions in the CM-SW field are attributed to foundational research or rather to specific industries / domains, and what kind of conceptual modeling languages are used. In line with the data analysis, it turned out that 38.6% of the publications collected were *foundational* research, whereas the remaining 61.4% were attributed to various specific industries. The most frequently occurring industries or Semantic Web activity areas, as they were called in the related taxonomy, were *manufacturing*, *IT*, *healthcare*, *education*, and *geographical information systems*. One paper could use one, several or even no conceptual modeling language(s). Among the conceptual modeling languages approximately 48% applied UML, and 26% any type of DSL. BPMN was used in 12% of the publications. Less than

[1]The institutions indicated are the ones at the time of publication of the respective papers.

10% used SWRL, OntoUML, SysML, ER[2], and OCL. Overall, more than 100 modeling languages were mentioned in the publications.

The fifth research question (**RQ5**) explored in what kinds of semantic technology segments and W3C main area did the contributions occur, what SW standard(s) they used. As far as semantic technology segments are concerned, the publications could refer to one, several or none of the segments. The data analysis revealed that 59% of the publications involved *semantic modeling and development*as a semantic technology segment. Around 25% of the publications referred to *learning and reasoning*, *semantic data management and integration*, *semantic annotation*, and *semantic collaboration incl. portal technologies* respectively. The steepest increase over the observed time period occurred in publications on *linked data* and *vocabularies*, when it comes to the W3C main area. The categories *queries* and *inference* have slightly increased in their presence, but at a lower level. With regard to the Semantic Web standards, again one, several, or no standard(s) was possible per publication. 68% of the publications used OWL, 52% RDF, which were the most used standards. Next, around 25% of the publications related to SPARQL and / or RDFS. For approximately 23% of the publications, no match with any of the SW standards in the taxonomy could be identified, which raised a topic for further research. Among the less frequently used SW standards were JSON-LD, RIF, SKOS, RDB2RDF, SHACL, SAWSDL, and RDFa.

The sixth research question (**RQ6**) aimed to explain what value added conceptual modeling can achieve in combination with Semantic Web. The data analysis showed that 67% of the papers achieved a benefit from *increment schema and modeling*, while 34% improved *interoperability of multimedia data*, 28% enjoyed greater *representation flexibility*, and 24% *enhanced* their *inference capabilities*. At the beginning of the observed time period, i.e. in the mid- to late 2000s up to around 2013, the number of publications per value added opportunity was approximately the same. But after 2013 the *incremental schema and modeling* as a value added has surged, while the remaining options were subject to a slower increase.

The seventh research question (**RQ7**) intended to combine several taxonomies to obtain more fine-grained mapping results and to reveal clusters emerging from the combined analysis. At this point, selected developments of combinations are summarized. Further combinations are covered in Section 6.4. The *combination of the contribution type with the modeling purpose taxonomy* indicates a concentration of papers along *representation* modeling purpose combined with *discussions* or *concepts* contribution type. The contribution type of *methods* rather appears in combination with the modeling purpose of *code generation* or *analysis*, and the contribution type *tools* is mostly combined with *code generation* as a modeling purpose. Over time notably the combination of *methods* with *representation* have grown considerably, as well as in general all of the largest combinations mentioned above. The taxonomy *combination of W3C main area with conceptual modeling language* reveals that the main areas *inference*, *linked data*, and

[2]Note: ER is here counted separate from the extended ER modeling language.

vocabularies are very often combined with the conceptual modeling language *UML* which is a general-purpose modeling language. In addition to this, *DSL* also appear to be used widely with regard to *linked data*, and *vocabularies*. The increase in the use of *DSL* in these combinations almost tripled over time, whereas the use of *UML* only doubled. The evolution over time hinted towards a growth in *inference* main area together with CML such as OntoUML, OCL, ER, DSL, AML and BPMN, as well as with *queries* in combination with UML, ER, and DSL. The *combination of the Semantic Web activity areas with the modeling purpose taxonomy* showed that an integral part of the publications concentrates in the foundational activity area in combination with the modeling purposes *representation* (79 publications), *analysis* (57), and *code generation* (39). Notably the modeling purposes *representation* and *analysis* prevailed across the activity areas. The largest part was in both analyzed time periods the category of *foundational* papers. The modeling purposes *representation* and *code generation* have become more extensive in combination with the activity areas *IT*, *manufacturing*, *healthcare*, and *education* over time. The *cultural* and *education* activity area stayed very small with regard to *representation*, *code generation*, and *analysis* as modeling purposes. The publications in the *tourism* activity area has grown stronger in combination with the modeling purpose *representation*, and *government* the other around. In addition to this, the *legal* activity area performed a shift from *code generation* to *representation* and *analysis* at a low level.

All in all, this thesis answered the research questions raised in the beginning throughout the steps of the systematic mapping study, and the related data analysis process. The SMS showed that the research area at the intersection of conceptual modeling and Semantic Web has grown from 2005 to May 2022, and likely will grow further, with an ongoing shift from conference papers to journal articles. The single taxonomy as well as the combined analysis indicated that some parts of the research area have been covered extensively, while others remained almost untouched, and could constitute potential opportunities for further research.

List of Figures

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Acronyms

AEC Architecture, Engineering, and Construction. 12, 13

AML Automation Modeling Language. 52, 54–56, 86

API Application Programming Interface. 20, 28

BPEL4WS Business Process Execution Language for Web Services. 31

BPMN Business Process Model and Notation. 4, 35, 44, 52–56, 82, 84, 86

CM conceptual modeling. 1, 3, 4, 6, 7, 9, 10, 14, 18, 20, 23, 29, 35, 50, 51, 82, 87, 89

CML conceptual modeling language. 44, 52, 54–59, 86, 87

DAML DARPA Agent Markup Language. 5

DOI Digital Object Identifier. 27, 28, 36

DSL domain-specific language. 4, 10, 11, 35, 44, 52–56, 82, 84, 86

EC exclusion criteria. 27

EPC Event-driven Process Chains. 4

ER Entity Relationship. 4, 11, 35, 44, 52–56, 82, 85, 86

GIS geographical information systems. 5, 47

GRDDL Gleaning Resource Descriptions from Dialects of Languages. 32

IC inclusion criteria. 27

IT information technology. 47, 59, 84, 86

JSON JavaScript Object Notation. 11, 32

JSON-LD JavaScript Object Notation for Linked Data. 32, 47, 53, 85

KG knowledge graph. 5

KOS knowledge organization system. 7

LAM library, archives, and museum. 7

ML machine learning. 6

NLP natural language processing. 6, 31

OCL Object Constraint Language. 35, 44, 52–56, 85, 86

ORM Object Role Modeling. 4

OWL Web Ontology Language. 5, 6, 11, 13, 31, 32, 42, 47, 52, 82, 85

POWDER Protocol for Web Description Resources. 33

PROV Provenance. 33

R2RML RDB to RDF Mapping Language. 33

RDB2RDF Relational Databases to RDF. 33, 47, 53, 85

RDF Resource Description Framework. 1, 5, 6, 11, 31–33, 47, 52, 82, 85

RDFS Resource Description Framework Schema. 1, 5, 6, 32, 47, 52, 85

RDFXML Resource Description Framework - eXtensible Markup Language. 6

RIF Rule Interchange Format. 5, 33, 47, 53, 85

RQ research questions. 2, 17, 80

SAWSDL Semantic Annotations for WSDL and XML Schema. 33, 47, 53, 85

SHACL SHapes And Constraints Language. 33, 47, 85

SKOS Simple Knowledge Organization System. 32, 47, 53, 85

SLR Systematic Literature Review. 7, 10–12, 14, 18

SMS Systematic Mapping Study. 2, 7, 9–14, 18–21, 23, 24, 27–29, 44, 63, 79–83, 86

SOA service oriented architecture. 31

SPARQL SPARQL Protocol And RDF Query Language. 5, 6, 31, 32, 47, 52, 82, 85

SW Semantic Web. 1, 7, 9, 11–14, 18, 20, 23, 29, 35, 36, 47, 49–51, 82, 85, 87, 89

SWRL Semantic Web Rule Language. 44, 82, 85

UI user interface. 3, 28

UML Unified Modeling Language. 4, 11–13, 35, 42, 44, 51–56, 63, 82, 84, 86

URI Uniform Resource Identifier. 1, 5

URL Uniform Resource Locator. 36

W3C World Wide Web Consortium. 1, 5, 18, 20, 23, 24, 29–32, 36, 45–47, 50–52, 54–57, 60, 82, 85, 87

WoS Web of Science. 10

WSDL Web Services Description Language. 31, 33

WWW World-wide Web. 4

XHTML Extensible Hypertext Markup Language. 33

XML eXtensible Markup Language. 5, 12, 13, 32, 33

XQUERY XML Query Language. 31

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Appendix

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