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Model-Driven Software Engineering: A Bibliometric Analysis

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ABSTRACT

Model-Driven Software Engineering (MDSE) is a software development methodology that reduces the cost and production time of the final product by concentratingon a higher level of abstraction. The main focus of MDSE is to generate automated code by applying different types of transformations to high-level models. The effectiveness of MDSE has been proved in different domains for solving various types of problems. This research provides the bibliometric analysis of research in the field of MDSE. The population of the study consists of all MDSE articles indexed in the Web of Science database in ten years from 2010 to 2019. The work aims to identify the volume of scientific production, the most influential countries, universities, authors, and journals, the cooperation network among the countries, universities, and authors, keyword ranking, and Co-word analysis of keywords and titles of the articles. Keyword analysis revealed that Model Transformation and Model Checking are two very important clusters and topics of interest to researchers in this field. The results provide valuable insights that can be used as a guideline by both fresh and experienced researchers for the current state and future trend of MDSE research in different scientific disciplines to establish a baseline beforeinitiating an MDSE research project in the future.

1 Introduction

One of the main focuses of the software engineering community is to reduce the cost of software development by concentrating on the higher level of abstraction and automating the process of product production [1]. Model-Driven Software Engineering (MDSE) is a revolutionary paradigm that reduces the development cost and provides a convenient way of software development [2] [3] [4] . Model is a central element in MDSE that presents a system under review from different perspectives. It is possible to generate automatic code from models in MDSE paradigm by applying different model-to-model and model-to-text transformations [5] [6].

A review of research in the field of MDSE identifies its increasing applications in different domains for solving a particular problem and finally automatic generation of code [7]. Some of these applications include the use of MDSE in the field of industrial applications [8][9], multi-agent systems [10][11], cloud computing [12–14], mobile applications [15][16], and

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embedded systems [17].

MDSE research is widely available nowadays, therefore presenting an overview of this research will result in a better understanding of this domain. Bibliometrics analysis is one of the commonly-used methods that retrieves statistical analysis and cooperation networks of quantifiable information in published scientific articles, books, and journals [18]. In 1969, Alan Pritchard first used the term 'Bibliometrics' in research entitled "Statistical bibliography or bibliometrics"[19]. He used this word to measure and analyze various aspects of scientific documents. Bibliometrics is a type of research method that uses a set of quantitative and statistical tools for analyzing books, articles, and other publications. It is possible to apply bibliometrics for all types of studies. There are no restrictions in this area and this technique can be applied wherever there exists a research dataset.

Scientific articles are indexed in large databases. This allows articles to be evaluated from various aspects such as total scientific output, influential authors, top journals, title analysis, abstracts and keywords, number of citations, and leading countries. The results of the analyses are displayed in various forms such as statistical tables, maps, graphs, or grids for better representation [20]. This type of bibliometrics analysis of articles enables us to better identify critical issues, emerging trends, and influential people in a field to make appropriate decisions for future research in that field [21]. There is a lot of research in the field of computer science and software engineering that used Bibliometrics studies. One of the first bibliometric researches in the field of software engineering is Hawkins's paper [22] on information retrieval systems. Firdaus et al. [23] analyzed 1119 blockchain articles indexed in the Scopus database between 2013 and 2018. This bibliometric analysis discovered that Switzerland and Singapore are two countries that receive many citations. Also, they found out that blockchain technology is able to solve security issues in the internet of things (IoT). Additionally, in [24–30], articles in the field of blockchain have been analyzed. In [31] the bibliometric approach is adapted to analyze 4070 papers relevant to big data research, which were published in the Scopus database between 2013 and 2018. Based upon 286 articles obtained from the Web of Science from 2000 to 2015, Zhang et al. [32] produced a literature review concerning big data and supply chain management. Nobre and Tavares [33] used the bibliometric method to explore the application of big data and IoT in the context of the circular economy from 2006 to 2015. Montelongo and Becker [31] reviewed 138 papers about Deep Learning publications in the legal domain, by manually searching for the terms: "Neural Networks" and/or "Deep Learning", in combination with "legal" or "law". In all these articles, similar methods have been used to evaluate the articles. the annual growth rate of the article, most frequent keywords, country collaboration, and most Prolific Countries are among the topics repeated in all articles.

Several articles have been published on the systematic review of MDSE. Due to the differences between the questions of this research and other articles, the results are different. In [17] 64 articles were reviewed in the field of MDSE and examined the goals, advantages, and challenges of MDSE. Nguyen et al. [34] studied MDSE methods for developing secure systems. They selected and reviewed 108 articles published in this field. One of the results of this research showed that most MDSE approaches focused on authorization and confidentiality. Additionally, Masmali and Badreddin [35] reviewed 56 articles in the field of model-driven security between 2008 and 2018. Bibliometric methods are now increasingly being used for research assessment. Bibliometrics tries to find semantic and mathematical relationships between scientific research with the help of mathematical, statistical, and text mining methods and software. Then the purpose of this article is to use the bibliometric method to analyze the scientific performance of articles, countries, authors, and journals based on the number of citations and cooperation networks, to mapping the state of the art, and identifying research gaps and trends in the context of MDSE. The results of this research contribute to an overall understanding of the concept of MDSE. Researchers who want to learn the MDSE become acquainted with journals, universities, countries, and top researchers in the field, and can be more aware of the choice of research path and to identify and cluster scientific gaps from most recent publications. Researchers will understand the extent of the connection between countries, universities, and authors, and will have better conditions for future research in research institutes. In this research, we analyze bibliometrics of all MDSE articles indexed in Web of Science by identifying the important areas of interest. The results are as follows: published year, publication type, authors and co-authors nationalities and the distribution of their continents, and the main contribution. To achieve the goal of the current study, the following questions will be answered:

RQ1 How is the quantitative trend of MDSE research?

RQ2 What are the top journals for publishing MDSE articles?

RQ3 Which countries have more cooperation and citation?

RQ4 Who are the top researchers and how do they

cooperate in the field of MDSE?

RQ5 Which universities have more articles and cooperation?

RQ6 What are the repetition rates of keywords and titles, and keyword analysis of articles?

Examination of index databases of various scientific texts showed that no work has been done on the analysis of MDSE articles in the field of bibliometrics techniques so far. For this reason, given the importance of studies in this field, in this research, we study this issue using bibliometrics techniques.

The rest of this paper is organized as follows. Section 2 describes the research method. The findings of the full analysis of bibliometrics and the answers to the questions are presented in Section 3, and the discussion and conclusion are given in Sections 4 and 5, respectively.

2 Research Methodology

The research methodology is an applied research bibliometrics technique. In the first stage of the bibliometrics process, a citation database is identified to receive the research information related to the MDSE field. Web of Science and Scopus are two main citation databases in the field of bibliometrics. The former is the older one and includes all Journal Citation Reports (JCR) [36] [37]. Therefore, the Web of Science database is used in this study. The dataset is compiled on June 15, 2020, and it includes all studies on MDSE published in journals indexed in the Web of Science database. The following research strategy was used to extract the data:
TS: ("Model-Driven Engineering" OR "Model-Driven Software Engineering" OR "Model-Driven Architecture" OR "Model-Driven Development" OR "Model-Driven Reverse Engineering" OR "Model-Driven Framework" OR "Model-Based Software Development" OR "Model-Based Software Engineering" OR "Model-Based Systems Engineering" OR "Model-Driven Approach")
Refined by: Document Types: (Proceedings Paper Or Review Or Early Access Or Article)
Timespan: 2010-2019.
Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI.

In this searching strategy and in the Topic Search (TS) section, the searched words in the title, abstract, and keywords of the articles are specified. In the sections of Refined by Timespan and Indexes the types of searched documents, the interval of search time, and the citation indexes are specified, respectively. After retrieving the related articles for MDSE in the timespan of 2010 to 2019 (ten-year period), 4914 search records are obtained. These articles are analyzed and the questions raised in the introduction part are answered after loading and integrating the data file. The BibExcel software [38] is used for frequency analysis, and to analyze the content and map of the research in this field, the VOSviewer software [39] is used, correspondingly. For quantitative analyses and bibliometrics, the Bibliometrix R Package Open Source Software is utilized. Figure 1 shows the process steps. The process of this study begins by using the main keywords in the Web of Science database. In the next step, the data were retrieved. Finally, the obtained data were analyzed with the help of bibliometric software and the results were reported.

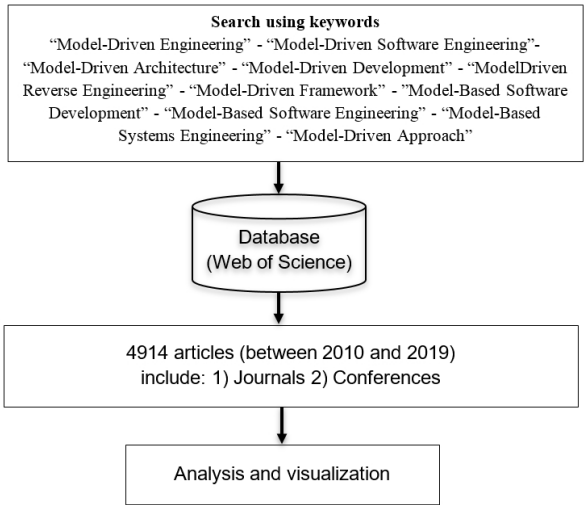

Figure 1. The Studying Process.

3 Research Findings

In this section, articles in the MDSE field are analyzed bibliometrically, and this method is applied to answer the research questions.

3.1 Quantitative Trend of Scientific Articles

In response to the RQ1, in the time interval between 2010 and 2019, 4,914 research records were published on the Web of Science in the domain of MDSE. Figure 2 shows the quantitative trend of MDSE research in the last decade. There had been some occasional decrease and increase in the trend of publishing articles in this time, but the overall growth has been slightly upward. With the publication of 590 articles, the largest number of articles in this field was published in 2016 after which a decrease in the number of articles was witnessed. This number of published articles has compared to the previous decade between 2000 and 2009 when 2126 articles were published in this field.

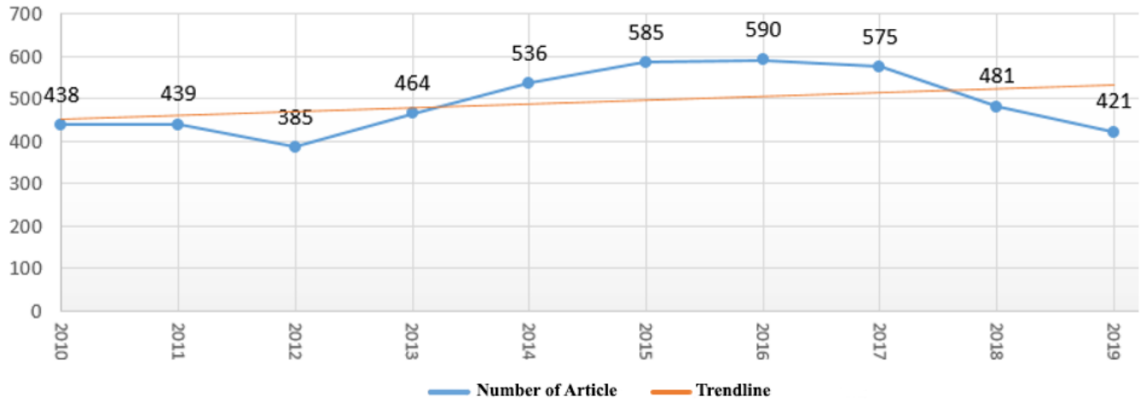

Figure 2. The Quantitative Trend of MDSE Research.

Table 1. Top MDSE Journals.

Rank	Name of Journal	ISSN	Number of Articles	Percent
1	Software and Systems Modeling	1619-1374	133	2.71
2	Journal of Systems and Software	0164-1212	68	1.38
3	Information and Software Technology	0950-5849	66	1.34
4	Science of Computer Programming	0167-6423	52	1.06
5	Systems Engineering	1520-6858	37	0.75
6	IEEE Access	2169-3536	30	0.61
7	Journal of Universal Computer Science	0948-6968	25	0.51
8	Computer Languages, System, and Structures	1477-8424	25	0.51
9	Software: Practice and Experience	1097-024X	24	0.49
10	Computer Science and Information Systems	2406-1018	21	0.43

3.2 Top Journals

In response to the RQ2, the findings show that in the ten-year interval between 2010 and 2019, there has been a total number of 2027 journals, conferences, and various book collections published in the field of MDSE.

The top three journals are ranked as SoSyM, JSS, and IST, with 133, 68, and 66 articles, respectively. Ten journals that have published the most number of research papers in the MDSE field are shown in Table 1.

Among the collections of books is Lecture Notes in Computer Science (LNCS) published by Springer with 559 articles in the MDSE field with a higher difference compared to other journals, conferences and, book collections. In this collection of books, valuable articles in MDSE have been published at prestigious conferences.

3.3 Status Network of Cooperation among Different Countries of the World

Sections 3.3 and 3.4 are in answer to the RQ3. Totally, 95 countries have participated in the publication of articles in the field of MDSE. Figure 3 shows the cooperation network among different countries in the MDSE field. Fifteen countries with the highest number of articles are included in this network. The size of the nodes indicates greater participation in the publication of articles, and the edges indicate the relationship among different countries in the publication of articles. The thickness of the edges indicates the degree of cooperation among countries. Germany, France, Spain, the United States, Italy, China, Canada, England, Austria, and Brazil have published the most articles in the MDSE field, respectively. Among them, Germany, Spain, and France had been more centralized than other countries in publishing articles. One of the things that makes a researcher more effective in a specialized field is how to interact with other researchers. The ability to influence others in this way gives that

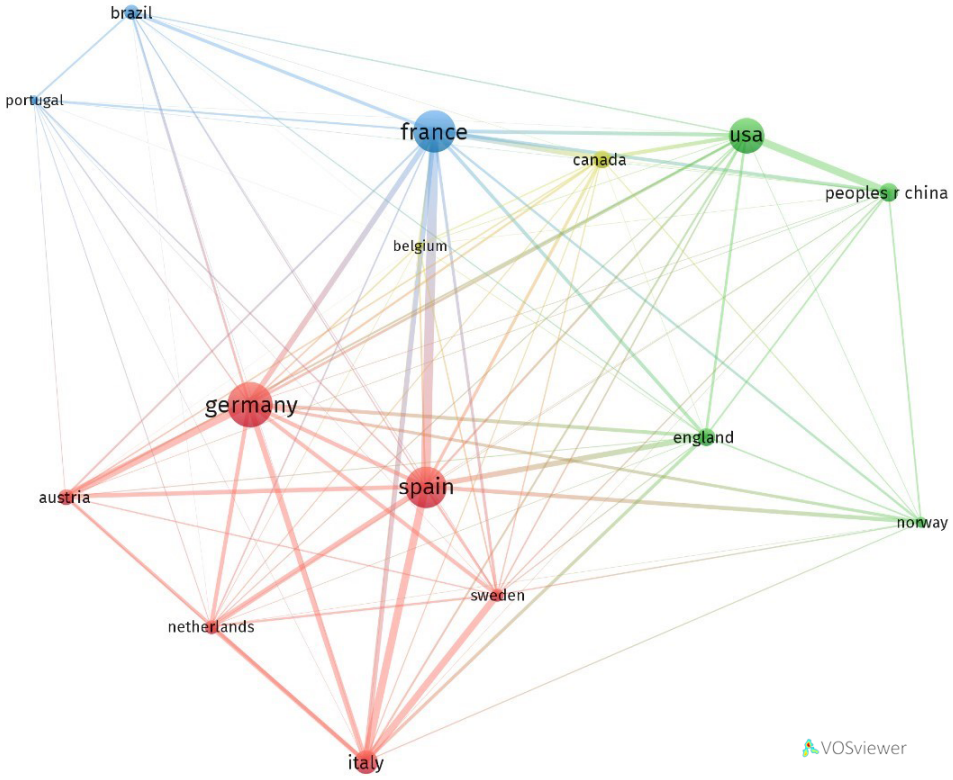

Figure 3. The Cooperation Network Among Different Countries in the MDSE Field.

Figure 4. Another View of the Cooperation Network Among Different Countries in the MDSE Field.

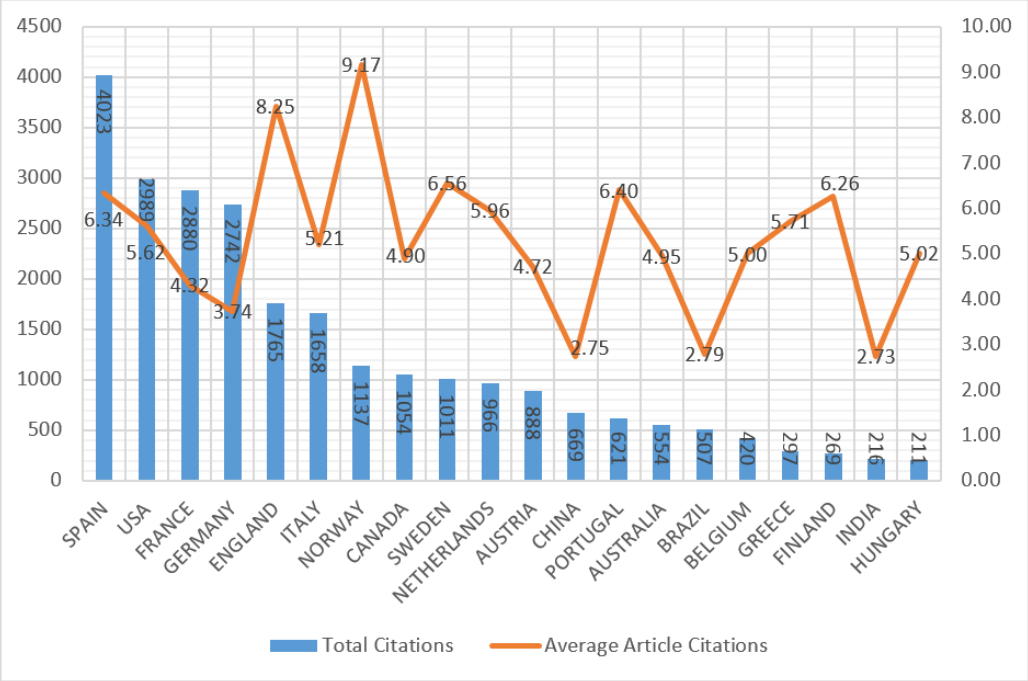

Figure 5. Countries That Have Received the Most Citations in the MDSE Field.

researcher greater social influence [40]. The more central a researcher is, the more interaction he or she has with other researchers, and the more influential he or she is. Additionally, a country whose researchers are more centralized has more influence in that field of research. These countries are considered influential nodes in the cooperation network among various countries and have high connections in producing articles with other countries.

Figure 4 shows another view of the cooperation network among different countries. The density of connections in the European continent indicates the cooperation of researchers in this continent with each other and researchers from other continents.

3.4 Countries with the Most Citations

Figure 5 shows 15 countries that have received the most citations in research in this area. According to the figure, although studies conducted by researchers in Spain, the United States, and France received the most citations in the articles in general, these studies had not received many citations on average. In terms of the average citations per article, the articles of researchers from Norway, England, and Sweden are cited more than the articles of researchers in other countries.

3.5 Top Researchers

In response to the RQ4, Sections 3.5 and 3.6 are stated. To evaluate the performance of researchers in bibliometrics, various indices such as the number of articles, the number of citations received and the H-index are used. Initial analyses show that a total number of 9430 persons participated in writing 4914 articles in this field in the last decade, of which 372 articles were written individually. The average participation per article was 3.51 and the average without considering articles written individually was 3.72. The average citation per article was 4.099. Table 2 shows the names of 16 researchers with the highest H-index in the MDSE field. The H-index considers two important indices of the number of articles and the number of citations simultaneously and evaluates the degree of effectiveness of a researcher [41]. For example, a researcher with an H-index of 20, has 20 articles that have received at least 20 citations. H-index specified for each researcher is only related to articles written in MDSE's field and does not cover other topics. Juan de Lara with ORCID 0000-0001-9425-6362 is the most active MDSE researcher in Web of Science, contributing to the publication of 67 articles. He also has the highest citation rate (709) and the highest H-index (15) among all researchers in this field. He is a professor at Univ Autonoma Madrid and his research fields are software engineering and MDSE. Although Esther Guerra with ORCID 0000-0002-2818-2278 ranks second in terms of the number of articles (56) and citations (681), her H-index is also 15. She is an asso-

Table 2. Top MDSE Researchers.

Rank	Researcher Name	Name of Institution	Country Name	Number of Articles	Number of Citation	H-INDEX
1	Juan de Lara	Univ Autonoma Madrid	Spain	67	709	15
2	Esther Guerra	Univ Autonoma Madrid	Spain	56	681	15
3	Jordi Cabot	Icrea	Spain	48	429	11
4	Manuel Wimmer	Johannes Kepler Univ Linz	Austria	47	340	11
5	Jesús Sánchez Cuadrado	Uni Murcia	Spain	28	311	11
6	Davide Di Ruscio	Univ Aquila	Italy	32	254	10
7	Richard F. Paige	Mcmaster Univ	Canada	27	226	9
8	Jon Whittle	Monash Univ	Australia	13	532	8
8	Esperanza Marcos	Rey Juan Carlos Univ	Spain	28	213	8
8	Dimitrios S. Kolovos	Univ York	England	24	195	8
8	Taentzer G	Univ Marburg	Germany	19	179	8
8	Daniel Varro	Mcgill Univ	Canada	21	161	8
8	Philip Langer	Eclipse Source Services Gmbh	Austria	10	137	8
8	Ivano Malavolta	Vrije Univ Amsterdam	Netherlands	14	117	8

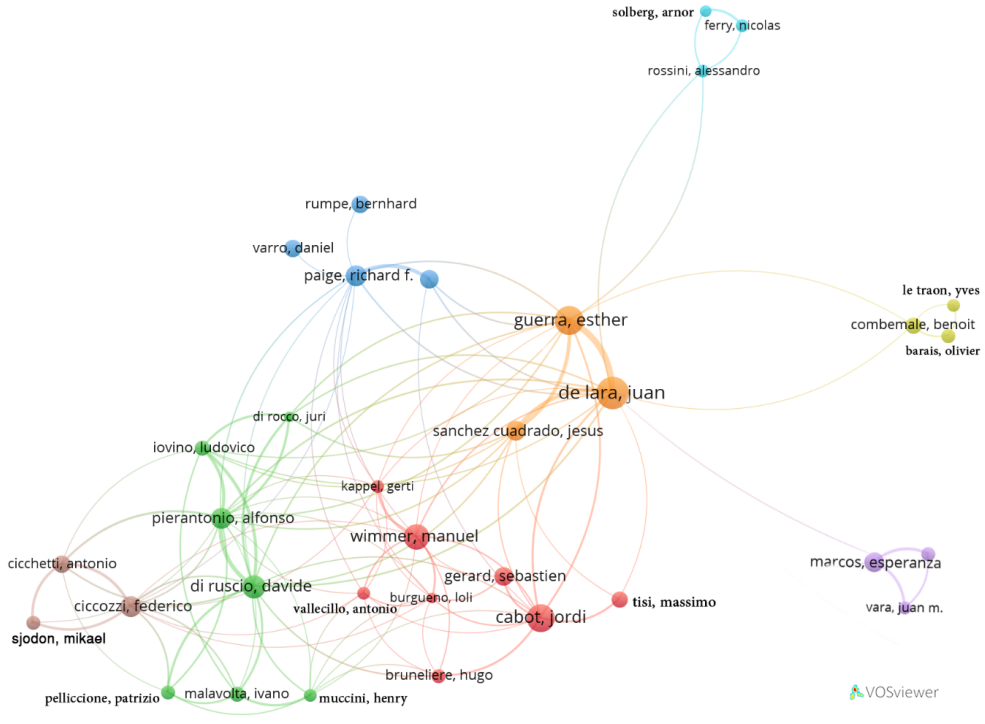

Figure 6. Co-Authorship Network of Researchers in the MDSE Field.

ciate professor at Univ Autonoma Madrid and Jordi Cabot with ORCID 0000-0003-2418-2489 ranks third with an H-index of 11. The interesting thing about this table is that four out of the top five researchers are from Spain.

Table 3. Number of Articles in Top MDSE Universities.

Rank	University Name	Country	Number of Articles
1	Univ Politecn Valencia	Spain	78
2	Univ Toulouse	France	76
3	Univ Autonoma Madrid	Spain	74
4	Tech Univ Munich	Germany	69
5	Politecn Milan	Italy	61
6	Vienna Univ Technol	Austria	57
7	Univ Aquila	Italy	56
8	Malardalen Univ	Sweden	53
9	Univ Castilla La Mancha	Spain	50
10	Univ Nova Lisboa	Sweden	47
10	Univ York	England	47

3.6 The Status of Cooperation among Researchers in Writing Articles

The cooperation network among authors shows the degree of cooperation among authors and the extent to which they influence the co-authorship network. Figure 6 shows the co-authorship network of researchers in this field (34 researchers with the highest citations are included in this network). The cooperation network among the authors led to the creation of eight clusters. Clusters indicate the cooperation of researchers in writing articles.

The largest cluster consists of eight researchers marked in red. Jordi Cabot and Manuel Wimmer are among the most influential researchers in the cluster. The second cluster of co-authorship is in green and includes seven researchers. Davide Di Ruscio and Alfonso Pierantonio are the most influential researchers in this cluster. The third cluster consists of four members and is blue. Richard F. Paige is the most influential researcher in this cluster. The other five clusters consist of three members. Juan de Lara, Federico Ciccozzi, Alessandro Rossini, Marcos Esperanza, and Combemale Benoit are among the most influential researchers in each cluster.

3.7 Top Universities

The answer to the RQ5 is given in Sections 3.7 and 3.8. In the publication of 4914 articles in the MDSE field, 2600 different universities and organizations have participated, among which the Univ Politecn Valencia of Spain with the participation of 78 articles ranks the first in the publication of articles in this field. Univ Toulouse of France and Univ Autonoma Madrid of Spain is in the second and third rank with 75 and 74 articles, respectively. Table 3 shows a list of the top 11 universities in the field of publishing MDSE articles. A review of the top universities shows that all universities are located in Europe and three of the 11 universities are from Spain and two are from Italy.

3.8 Cooperation Network of Top Universities

Figure 7 shows the network of cooperation among the top universities in the MDSE field. There are 20 influential universities in this field, which have comprised three clusters. Two clusters are marked in red and green with eight universities and one cluster in blue with four universities. Clusters indicate the cooperation of universities in a cluster in writing articles. In the red cluster, Univ Nova Lisboa from Portugal and Univ Twente from the Netherlands are the influential universities in the inter-university cooperation network. In this cluster, Vienna Univ Technol and Johannes Kepler University Linz universities have cooperated extensively in writing articles in the MDSE field. In the green cluster, Univ Autonoma Madrid from Spain is considered the most influential university. This university has worked extensively with Univ York Uk. In the blue cluster, the Univ Aquila universities in Italy, and the universities of Malardalen Univ, Univ Gothenburg, and Chalmers Univ Technol in Sweden have co-authored articles in the MDSE field.

Figure 8 shows a 3-field plot view of the relationship among universities, countries, and authors. On the left, middle, and right sides are the names of the authors, countries, and universities, respectively. In Spain, four universities of Univ Politecn Valencia, Univ Autonoma Madrid, Univ Castilla La Mancha, and Univ Alicante play a key role in the production of articles in the MDSE field, and Juan de Lara, Esther Guerra, Jordi Cabot, Oscar Pastor, Jesús Sánchez,

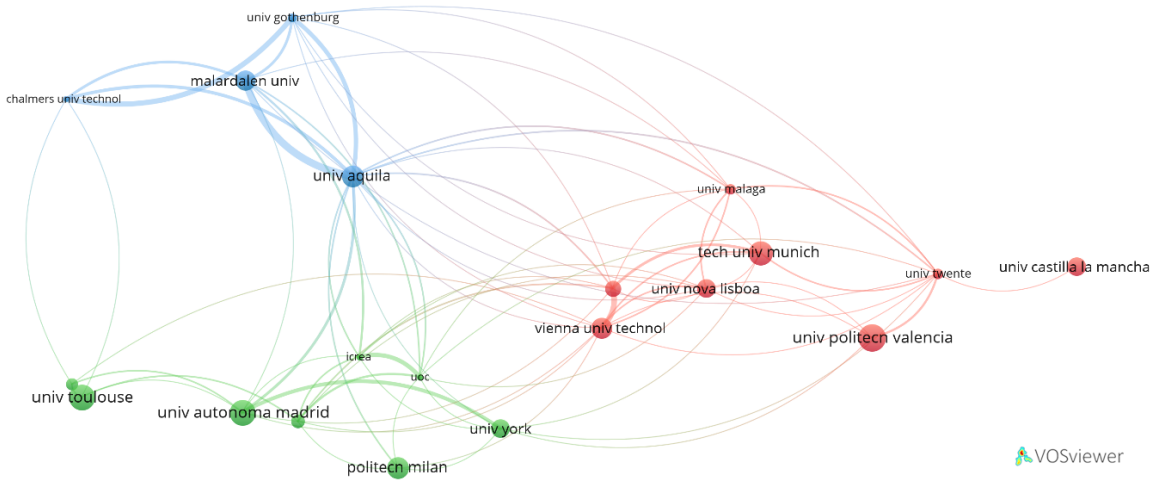

Figure 7. The Network of Cooperation Among the Top Universities in the MDSE Field.

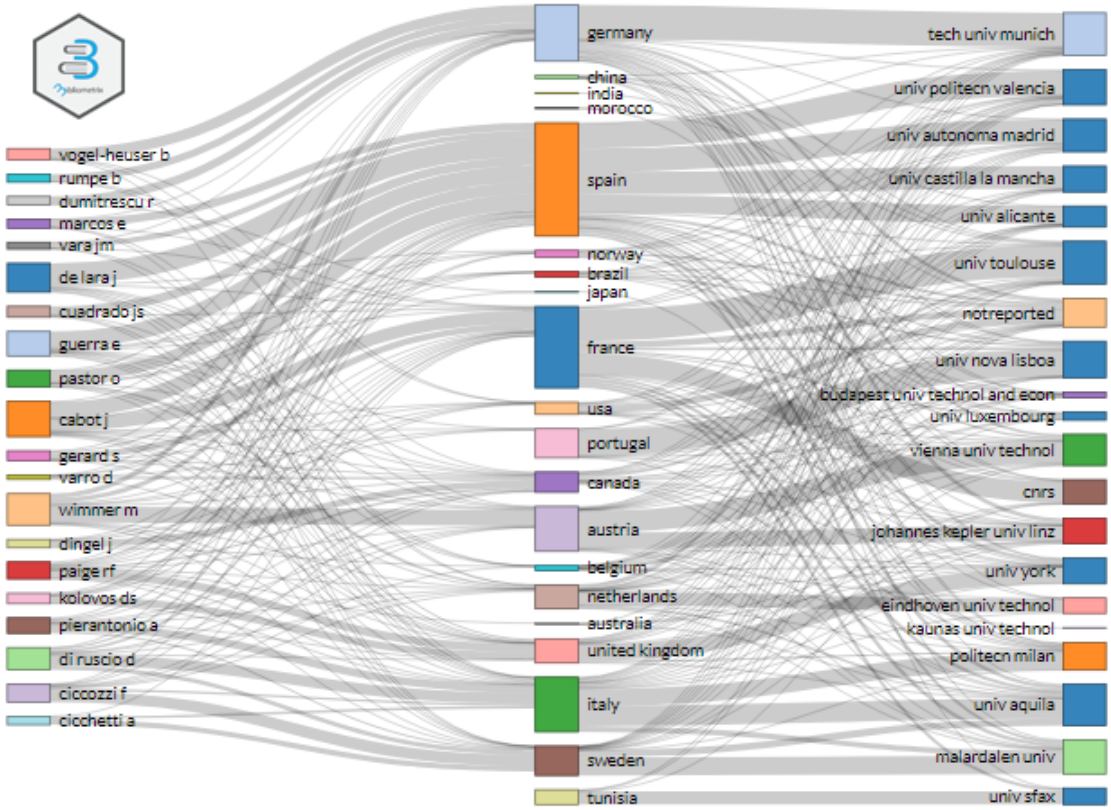

Figure 8. 3-Field Plot View of Authors, Countries, and Universities in the MDSE Field.

Table 4. Most Frequent the MDSE Field Keywords.

Rank	Keyword	Repetition	Percent	Rank	Keyword	Repetition	Percent
1	Model-Driven Engineering	1230	6	11	Cloud	152	0.74
2	Model-Driven Development	783	3.82	12	SysML	135	0.66
3	Model-Driven Architecture	560	2.73	13	Business Process	120	0.59
4	Model Transformations	398	1.94	14	Mobile	94	0.46
5	UML	289	1.41	15	Model Based	91	0.44
6	Metamodel	288	1.41	16	Systems Engineering	90	0.44
7	Model-Based Engineering	263	1.28	17	Software Engineering	88	0.43
7	Domain Specific Language	263	1.28	18	Component-Based	82	0.4
9	Code Generation	172	0.84	19	Modeling	76	0.37
10	Ontology	158	0.77	19	Embedded System	76	0.37

Cuadrado Esperanza Marcos, Juan Manuel Vara, and Manuel Wimmer are among the most prolific authors in the country. Jordi Cabot and Manuel Wimmer are also the most prolific authors in France and Austria, respectively.

3.9 Keywords Ranking in MDSE Field Based on Frequency

In response to the RQ6, Sections 3.9, 3.10, and 3.11 are mentioned. To answer this question, first all the keywords of the articles under study were standardized. For example, keywords that were both singular and plural or were synonymous in terms of concepts were modified and selected in a single unit. For example, the keywords Query View Transformation and QVT were written as a single QVT, or the keywords Modeling Language and Modeling Languages were written as Modeling Language. The keywords obtained from the articles were 5835 keywords used, exclusively. These keywords have been repeated for a total number of 20487 times. On average, each article had 4.17 keywords which were analyzed using bibliometrics tools. Table 4 shows the results for 20 most common keywords in the MDSE field. The keywords Model-Driven Engineering, Model-Driven Development, and Model-Driven Architecture have the most repetition frequencies among the studies in this field. These keywords are of the main concepts in the MDSE field, and their frequency counts seem obvious due to their use in the search strategy. The keyword Model Transformations ranks fourth with 398 repetitions. UML and Metamodel are next in rank with 289 and 288 repetitions, respectively. Among the applications of MDSE, Cloud, Mobile, and Embedded System are mentioned among the top 20 keywords.

3.10 Title Analysis based on Word Cloud

In this part of the research, based on the frequency of words used in the titles of articles, 100 words were selected and a super word image was prepared (Figure 10). The size of the words in the image indicates their frequency. For example, the words Model, Systems, and Engineering are larger than other words, indicating that they have the highest frequency among the MDSE research field.

3.11 Co-word Analysis

In the clustering process, 113 keywords that had at least 20 frequency counts were entered into the final stage. To have a better presentation of output, some keywords were abbreviated, for example, the Model-Driven Engineering keyword was abbreviated to MDE. First, the co-occurrence file of these 113 keywords was prepared using Bibexcel software. Figure 9 shows the co-occurrence network of keywords in this field. This network is drawn with VOSviewer software [39]. VOSviewer uses a technique for mapping and clustering of bibliometric networks that unifies the VOS mapping technique with a weighted and parameterized variant of modularity-based clustering [42]. The results of keyword clustering led to the creation of nine clusters. Each cluster is marked with a different color and the highly repeated words have a larger font size.

The largest cluster contains 24 keywords, highlighted in purple in Figure 9. Keywords in this cluster include M2M Transformation, Model Transformation, QVT, Bidirectional Transformation, Graph Transformation, and ATL. In this cluster, model transformation issues are the key issues. As mentioned in the introduction, model transformation is one of the main components of the MDSE process.

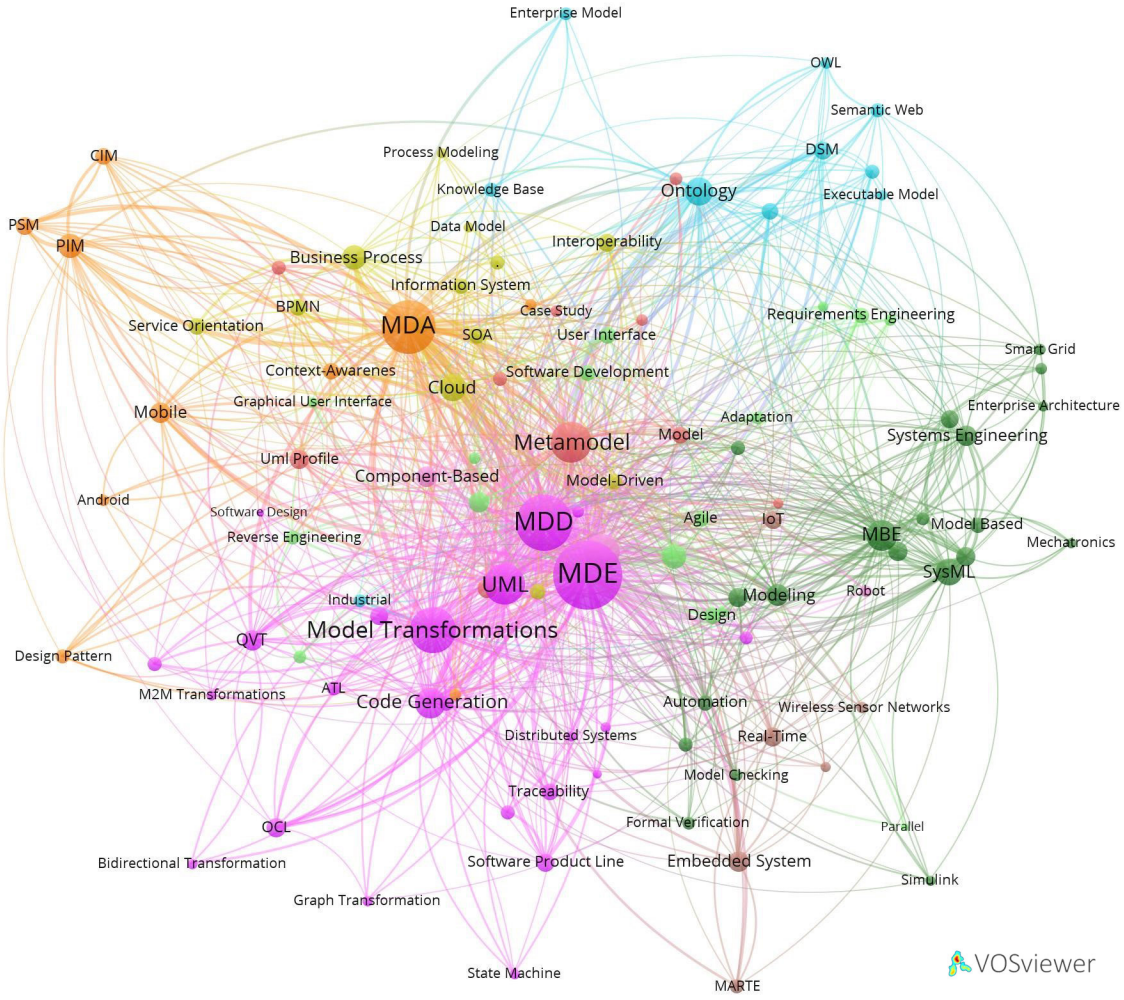

Figure 9. The Co-Occurrence Network of Keywords in the MDSE Field.

The second cluster contains 20 keywords highlighted in dark green. In this cluster, keywords such as MBE, Modeling, SysML, Model Checking, Model-Based, and Enterprise Architecture can be seen, which refers to a modeling issue that is considered as one of the MDSE phases.

The third cluster was highlighted in light green and contains 16 keywords. This cluster deals with topics such as User Interface Design, Web Applications, the use of Agile Methodology, and Requirements Engineering.

Cloud computing is the most important keyword of the fourth cluster (yellow), which is next to the keywords of service-oriented architecture (SOA) and service orientation. Cloud computing architecture is based on service-oriented architecture and supports service orientation [43]. Some other keywords in this cluster include business processing management system, business process, and web service.

Keywords in the fifth cluster marked in red include Metamodel, Model, Case Study, Big Data, Data Warehouse, and Security. This cluster deals with model-driven applications in metadata and security issues.

The sixth cluster consists of ten keywords with blue nodes. Keywords in this cluster include OWL, Ontology, and the Semantic Web.

The seventh cluster is related to model-driven applications in mobile and Android and is marked in orange. Keywords in this cluster include Android, Mobile, CIM, PIM, and PSM.

The eighth cluster is marked brown and is linked to the development of model-driven in the fields of Modeling and Analysis of Real-Time and Embedded Systems (MARTE), the Internet of Things, and Wireless Sensor Networks. The keywords of this cluster are MARTE, Embedded System, Real-Time, IoT, and Wireless Sensor Network.

The ninth cluster has three keywords. These keywords are DSL, component-based, and robot.

4 Discussion about the Research Questions

This section answers the questions proposed in the introduction section. The quantitative trend of article production is shown in Figure 2. In the last decade, an average of 491.4 articles are published each year. In the interval time between 2014 and 2017, there is the highest number of articles in the MDSE field, with an average of 571.5 articles published in these four years. The number of articles decreased from 2010 to 2012 and then until 2016, we see an increase in articles. Since 2017, the number of articles has decreased with a slower slope. Since the growth trend of articles in these ten years has been intermittent, it is predicted that this growth will be increasing again after 2020.
The journal of Software and Systems Modeling (SoSyM) with 136 articles and almost double the difference compared to other journals lies in the first rank of journals in this field, followed by Journal of Systems and Software (JSS) and Information and Software Technology journal (IST) with 69 and 66 articles, respectively. SoSyM is an international journal that focuses on theoretical and practical issues covering the development and application of software and system modeling languages and techniques.
JSS and IST publish topics related to software engineering and software development. Germany, Spain, and France have published the most article in this field, and these countries have had the most cooperation with other countries in the production of articles. Among them, the highest rate of cooperation among researchers was reported between the Spanish, French, and Italians, the US and Chinese, Germans and Austrians, and Swedish and Italians among other countries. In terms of citations, Spain, the United States, France, and Germany received the highest citations in this area with 3435, 2834, 2576, and 2442 citations, respectively. Although Norway ranks seventh in terms of citations with 1,056, it ranks first with an average of 9.17 citations per article, followed by England and Sweden with an average of 8.25 and 6.56, separately. Juan de Lara and Esther Guerra, professors at Univ Autonoma Madrid in Spain, overtake other researchers in terms of the number of articles, citations, and H-index, respectively, and rank second among MDSE researchers. Among the top 14 researchers in the field are five from Spain and two from Austria and Canada.

From the cooperation of 34 top researchers in this field, eight clusters of cooperation were obtained. Researchers including Jordi Cabot and Manuel Wimmer, Davide Di Ruscio, Alfonso Pierantonio, Richard F. Paige, Juan de Lara, Federico Ciccozzi, Alessandro Rossini, Marcos Esperanza, and Combemale Benoit are among the most influential researchers in each

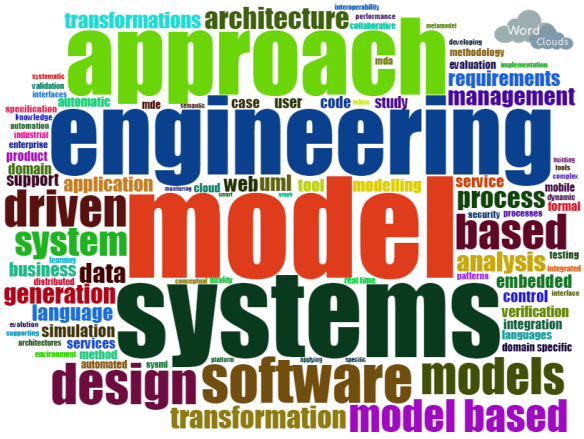

Figure 10. Word Cloud With 100 Recurring Words in the Titles of MDSE Articles.

cluster. Spanish universities play an influential role in MDSE research, with Univ Politecn Valencia, Univ Autonoma Madrid, and Univ Castilla La Mancha ranking first, third, and ninth, respectively. Univ Toulouse in France ranks second. The top 20 MDSE universities are in three clusters. In different clusters, Univ Nova Lisboa and Univ Twente, Univ Autonoma Madrid, Univ Aquila, and Malardalen Univ are among the influential universities in the network of cooperation of top universities. Overall, Spain can be considered the most influential country in the field of model-driven studies. It is a pioneer in this field and many universities and researchers from this country are working in this field. Figure 9 shows the MDSE domain keywords. Model-Driven Engineering, Model-Driven Development, and Model-Driven Architecture are the most frequently used keywords in this field. These keywords are the main words of the MDSE and their repetition is obvious. In the following, the keywords Model Transformations, UML, and Metamodel are repeated the most. Model transformations are the heart and soul of MDSE [45]. Model transformation is used to convert models to other software artifacts like code. Metamodeling is a fundamental part of model transformation design as it allows the structural definition of modeling languages. Having an accurate metamodel is a prerequisite for the correct and automatic execution of the model transformations. A UML model can graphically depict a certain level of abstraction and system structure and behavior from a certain viewpoint. Nine thematic clusters of keywords were made. In these clusters, the most important issues mentioned in MDSE articles and applications were identified. The largest cluster deals with transformation concepts. Much of the model-driven articles deal with transformation issues, types of transformation, and related challenges. Transformations are usually developed using specific languages e.g. ATL. In this cluster, these issues are also addressed. The second cluster deals with model

issues. This cluster contains articles examining modeling languages such as SysML, Model Checking, and modeling with various tools. Model is the most important artifact in MDSE, so the issues related to the model are very important. Other clusters deal with MDSE applications in various domains. The MDSE helps mobile developers build mobile apps for different platforms without paying attention to technical details. It allows developers to focus on design quality rather than implementation issues. The other important clusters include IoT, Cloud computing, Big Data, Embedded Systems, Wireless Sensor Networks, and Web Applications.
Figure 10 shows the 100 most frequently used words in the titles of articles in this field. The words Model, Systems, Engineering, and Approach are the frequently used words in the titles of MDSE articles.

5 Conclusions

To provide a comprehensive perspective of worldwide research in MDSE, this study offered a bibliometric review of documents indexed in WOS during 2010-2019. This kind of overview would be helpful to the MDSE academic community. The results of studies in bibliometrics show that in the last decade, the growth rate of MDSE articles has had occasional changes. This part of the results is consistent with findings by Abouzahra et al. [44]; they showed that publications in this filed are spread over time. Moreover, Nguyen et al. [45] indicated that the number of papers in Model-Based Security Engineering found by search engines sharply increased from 2001 to 2016. Nevertheless, findings by Mohamed et al. [46] showed that MDSE is an active research area with an increasing number of publications over the years. A total number of 95 countries have participated in publishing articles in this field, of which, European countries have invested the most. Germany, Spain, and France have the most articles in this field by far compared to other countries. This is consistent with the findings by Mohamed et al. [46] that showed. Leading countries can be considered in proportion to the number of articles published and the population of that country, which we have not considered in this article. In terms of citations, Spain, the United States, France, and Germany received the highest citations in this domain, respectively. However, in terms of average citations per article, Norway ranks first, followed by England and Sweden. The journal of Software and Systems Modeling is in the first place in publishing by far in this field. Germany, China, France, and Spain have had the most cooperation with other countries in publishing MDSE articles. Juan de Lara and Esther Guerra are the most influential researchers in this field. These two researchers are professors at Univ Autonoma Madrid. Univ Politecn Valencia from Spain and Univ Toulouse from France which are the first and second top universities in the MDSE field. The most important keywords in the articles, include Model Transformations, UML, and Metamodel. The analysis of keywords in this field led to the creation of nine clusters that "Transformation" and "Model" are among the most important issues mentioned in those clusters. The results indicate that MDSE researchers are still focused on extending the concepts of Transformation and Modeling and applying MDSE to variety of domains. As seen in this article, Bibliometrics research has been conducted in various domains of software engineering Such as IoT, Big Data, Blockchain, and Deep Learning. However, there is still some room for more research. Given the importance of issues such as security and privacy in computer systems, conducting bibliometric studies in the field of security and privacy of these systems can be considered as future research.

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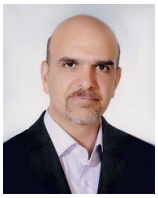

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