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Knowledge management frameworks in software engineering: A mapping study

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Abstract

Knowledge is an important resource that enables organizations to survive in an ever-changing environment. The basic conceptual structure that describes the processes of internal knowledge transfer and transformation is a knowledge management framework, which serves as a foundation for an effective knowledge management strategy. Software engineering processes have some inherent knowledge management in them, but the process alone does not adequately address knowledge management.

The main research question was what kind of research has been done on knowledge management frameworks in software engineering. Three assisting research questions were formed to answer the main research question: What types of papers are being published? What are the keywords covered by the knowledge management framework publications? What types of scientific contributions have the publications made?

This thesis used mapping study to get an overview into the research efforts made regarding knowledge management frameworks in software engineering. The study used 76 papers from the database of Institute of Electrical and Electronics Engineers (IEEE), which were examined and assigned to multiple categorization schemes, which included research type, keyword coverage, research context, contribution facet and the knowledge management framework type. These resulting categorisations were used to determine the answers to research questions and give insight into the efforts made on knowledge managements frameworks.

The results suggest that the efforts on knowledge management frameworks have been consistent over the last 20 years with a peak that corresponds to the popularity trend of research on knowledge management. The publications have been emphasizing few key areas in each categorization scheme. The areas that lack publications are identified, which indicate a research gap.

Keywords
Knowledge Management, Knowledge Management Framework, Mapping Study, Software engineering

Supervisor
PhD, University Lecturer Raija Halonen

Foreword

The course that made me interested in knowledge management was a couple of years ago and this thesis that is the result of that initial spark is finally completed. I am very thankful to everyone involved with me during this process for their patience and support. I wish to thank Professor Raija Halonen for supervising and advising me during the writing process, Tonja Molin-Juustila for additional advice and support, Paavo and Henri for keeping me in shape and my family for keeping me motivated.

Juho Mikkola

Oulu, April 20, 2021

Contents

1. Introduction

The purpose of this thesis was to examine the research performed on knowledge management frameworks in software engineering. The motivation for the study was the interest of the author and the suspicion and view that there has been no mapping study conducted on the research of knowledge management frameworks.

The objective of this thesis was to create an overview into the efforts on knowledge management frameworks research in the field of software engineering. The foundation of the research method used in this thesis was a mapping study that followed the process by Petersen, Feldt, Mujtaba and Mattson (2008). The aim of this study was to provide an overview of scientific papers in the research area. The overview identifies areas suitable for conducting a systematic literature review (Kitchenham & Charters, 2007) and gives insight on the efforts on knowledge management framework research.

The categories used for the classification of the studies were formed to answer the assisting research questions and the results were presented to answer the main research question:

- What kind of research has been done on knowledge management frameworks in software engineering?

The assisting research questions in this study used to answer the main research question and to establish the categorization scheme in the mapping study were:

- RQ1: What types of papers are being published?
- RQ2: What are the keywords covered by the knowledge management framework publications?
- RQ3: What types of scientific contributions have the publications made?

The main contribution of the research was to present properties of the research efforts done on knowledge management in the software engineering field.

This study uses the following structure: First, the literature on the subject matter is examined to give definitions to the core terms and facilitate the formation of the research questions. Second, the research method is described and applied to the material. Third, the results of the mapping process are reported. Fourth, the findings are discussed and finally the concluding remarks are given.

2. Prior research

The prior research examined in this chapter is to provide an overview on the theories of the underlying concepts in knowledge management and describe findings of prior research in the field. This information is used to develop the categorization schemes. Chapter 2.1 describes the foundational concepts of knowledge and knowledge management. Chapter 2.2 describes knowledge management frameworks that are used as the main artefacts examined in this study. Chapter 2.3 describes software engineering and the prior research done on knowledge management frameworks in software engineering context.

2.1 Knowledge and knowledge management

Knowledge is a valuable organizational resource, that is essential for value creation and establishing a competitive advantage. Knowledge combines individual or collective understanding that gives people the ability to draw meanings in a particular context. (Newell, 2015.) This manifests itself through organizational culture and identity, routines, policies, systems, and the capabilities of individual persons (Alavi & Leidner, 2001). The fluid and intangible nature of knowledge makes measurement difficult (Ragab & Arisha, 2013).

Knowledge in organizations is in two forms, tacit and explicit. Explicit knowledge is knowledge that can be transmitted easily trough systematic manners, such as documents, books, and databases. (Nonaka, 1994.) Tacit knowledge is subjective information that people possess (Hislop, Bosua & Helms, 2018) such as intuition and insights in a specific context, which makes it is hard to formalize (Nonaka, 1994). Tacit knowledge can be stored by a process of codification, but it is more time-consuming and difficult than sharing explicit knowledge (Hislop et al., 2018). The interactions and conversions between the types of knowledge are Socialization (tacit to tacit), Externalization (tacit to explicit), Internalization (explicit to tacit) and combination (explicit to explicit) (Nonaka, 1994) as depicted in Figure 1.

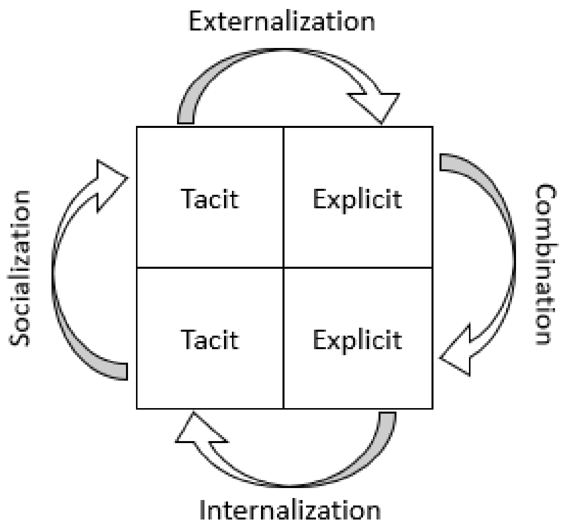

Figure 1. Conversions between the different types of knowledge (Nonaka, 1994).

The relationships between tacit and explicit knowledge and their nature are challenged by the objectivist and practice-based viewpoints. In the objectivist perspective the relationship between tacit and explicit knowledge is that they are strictly separate, and that knowledge is purely cognitive, and the management of this knowledge is addressed by creating mechanisms for codification. In the practice-based perspective there are tacit and explicit aspects to every kind of knowledge that is embedded in all activities that are carried out, and the managerial focus shifts on the communication and interactions. (Hislop et al., 2018.) Knowledge management is the multifaceted and multidisciplinary process (Alavi & Leidner, 2001) that entails the management of the creating, sharing, and applying knowledge and fosters best practices that facilitate organizational learning (Dalkir, 2017).

Using technology can support embedding knowledge into the organizational processes and routines. The systems that the organization uses exhibit the norms and expectations that the organization holds by becoming examples of desired outcomes. This leads to organizations doing the same things that they have done, but more effectively, with eventual diminishing returns. On the other hand, radical and continuous change in the challenges that the organization faces require the continuous evaluation and renewal of the underlying assumptions that are the foundations of the established processes. (Alavi & Leidner 2001.)

2.2 Knowledge management frameworks

A knowledge management framework explains the knowledge management elements, their relationships, and principles (Weber, Wunram, Kemp, Pudlatz & Bredehorst, 2002). The frameworks can be classified to prescriptive and descriptive, with the prescriptive ones being more commonly proposed by researchers (Rubenstein-Montano, Liebowitz, Buchwalter, McCaw, Newman, Rebeck & Team, 2001). Prescriptive frameworks describe how organizations should structure knowledge management implementation guidelines (Jennex, 2007) and direct the procedures how to implement knowledge management in the organization (Sumathi, 2016). Descriptive frameworks characterize the nature of the knowledge management phenomena (Jennex, 2007) and identify important attributes of knowledge management that contribute to the success or failure of the knowledge management effort (Sumathi, 2016). Descriptive frameworks can be further divided into broad and specific categories depending on their breadth and depth (Holsapple & Joshi, 1999). Hybrid frameworks, that include elements of both prescriptive and descriptive frameworks describe activities that lay the groundwork for double-loop learning, which is facilitated by feedback and other interactions in the organization (Rubenstein-Montano et al., 2001). The recommended framework is both descriptive and prescriptive, consistent with systems thinking, links the organizational goals with knowledge management and directs the organization to plan out the activities before engaging in them (Sunassee & Sewry, 2002).

2.3 Knowledge management in software engineering

Software engineering is the practice of using quantifiable, systematic, and disciplined practices in the development, operation, and maintenance of software (Bourque & Fairley, 2014), which can be improved with applying knowledge management practices to them (de Vasconcelos, Kimble, Carreteiro, Rocha, 2017). The knowledge in software engineering is dynamic and evolves together with the environment that the activities are performed in (Ward & Aurum, 2004), but organizations have problems identifying the properties of the knowledge and how it should be applied effectively (de Vasconcelos et al., 2017). The degree of usage of the tools used for knowledge management varies depending on the different organizational groups, developers preferring more specific knowledge and managers more abstracted knowledge (Sholla & Nazari, 2011). Software engineering processes have some inherent knowledge management activities in them without using a uniform model, but those processes alone do not address knowledge management effectively (Ward & Aurun, 2004).

During the years 1974 and 2017 there were 7628 publications in the field of knowledge management. The increasing interest in the field had its largest gain in popularity in the year 2000, which continued until the peak in 2012 and has steadily declined thereafter. (Wang, Zhu, Song, Hou, Zhang, 2018.) The research efforts in knowledge management in software engineering differs from the more mainstream research on knowledge management in that it is more directed at the topics of storage and retrieval of knowledge instead of knowledge creation and transfer (Bjørnson & Dingsøyr, 2008). There have been multiple mapping studies on knowledge management in software engineering that have examined the field, which cover topics such as the application of knowledge management approaches to software architecture (Li, Liang & Avgeriou, 2014), the usage of Kanban method in software engineering (Ahmad, Dennehy, Conboy & Oivo, 2017), software development in start-up companies (Paternoster, Giardino, Unterkalmsteiner, Gorschek & Abrahamsson, 2014) and knowledge management initiatives in software testing (Souza, Falbo & Vijaykumar, 2014).

Most of the contribution types of the research in knowledge management in software engineering are of the weak type (lessons learned, tools and guidelines) with 63% of the papers belonging to that group as opposed to the 37% of the papers presenting a strong contribution type (theory, framework, and method) (Paternoster et al., 2014). There is no clear preferred forum for publications on Knowledge management initiatives in software testing. The publication forums have mostly been conferences with 60% of the results, followed by 33% in journals and 7% in workshops. (Souza et al., 2014.)

In software product line testing context, the most frequent research type is solution proposal (41%). The smaller categories are validation (19%), conceptual proposal (17%), evaluation (14%), experience (3%), and opinion (6%). Compared to the number of proposed solutions there is a lack of actual usage and evaluation of these proposals. (Engström & Runeson, 2011.) In the context of software development in start-ups the research type of evaluation research is the largest (49%), followed by experience papers (21%), solution proposals (16%), philosophical papers (9%) and opinion papers (5%) (Paternoster et al., 2014).

The most frequently used knowledge management keywords are related to the sharing, innovation, learning, transfer, systems, ontologies, creation, information technology, information systems and organizational culture. These results show that the knowledge management research is focused on knowledge acquisition and sharing to improve the performance of the organization. The most cited papers in knowledge management were published during the years from 1995 to 2010, which can be explained by the rise of the subject matter in popularity during those years and the fact that the more recent papers require 13-15 years to reach the maximum number of citations. (Wang et al., 2018.)

3. Research method

In this chapter the research method used in this study and its application are described. Chapter 3.1 describes the mapping study and presents different methods of examining different properties of studies, which are used as ways to classify them. Chapter 3.2 details the application of the method in this study by describing the research questions and how the research was conducted.

3.1 Mapping Study

The mapping study (sometimes termed a scoping review) is a research method that can identify suitable areas for systematic literature reviews (Kitchenham & Charters, 2007). They are used to determine what sorts of studies have been carried out related to the research question (Bailey, Budgen, Turner, Kitchenham, Brereton & Linkman, 2007). The goal of a systematic mapping study is to allow the presentation of the results in a visual way and the categorization of the results to a map, providing a coarse overview that identifies research gaps. The systematic map that results from mapping studies is a more visual way to summarize the results, which helps transferring the results to practitioners in a more appealing way. Conducting a systematic mapping study executes its phases in a linear order and their outcomes are linked to the subsequent phases. (Petersen, Feldt, Mujtaba & Mattsson, 2008.) The process of systematic mapping study is depicted in Figure 2.

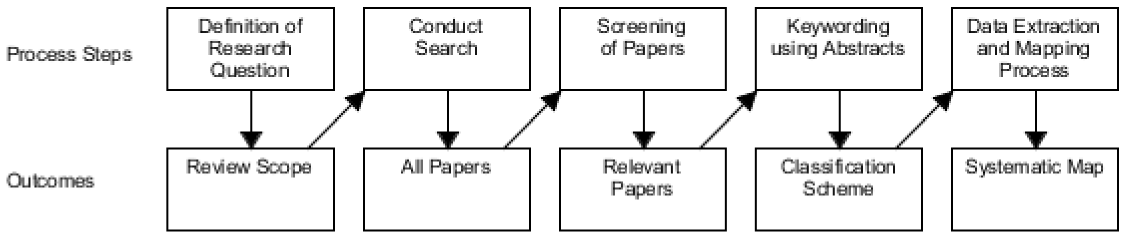

Figure 2. Process for a systematic mapping study in Software Engineering (Petersen et al., 2008).

Mapping studies facilitate Systematic literature reviews (Kitchenham & Charters, 2007). The method focuses on the research on the topic to show where evidence is missing or not sufficiently reported and examines the papers in a more rigorous fashion (Petersen et al., 2008). Systematic Literature reviews are conducted in three general phases: (i) Planning, which involves establishing the review protocol by defining research questions, the inclusion and exclusion criteria, the sources of studies, the search string and mapping procedures; (ii) Conducting, which involves searching and selecting the studies to extract and synthetize data from them; (iii) Reporting, which involves reporting the results and answering the research questions. Mapping studies follow a similar process but have broader research questions and data extraction processes and tend to return a larger number of search results. The results do not contain in depth analysis on the subject matter and rather give a graphical representation on the research results. (Kitchenham & Charters, 2007.) The scope of the mapping study can be limited by choosing the topic in a way that ensures a manageable number of 'hits' tailored to the timescale and needs of the study. In addition, the searches may be limited to the databases such as Association for Computing Machinery (ACM) and Institute of Electrical and Electronics Engineers (IEEE). (Budgen, Turner, Brereton & Kitchenham 2008.)

Typically mapping studies are believed to be conducted based only on the abstracts, but some in depth study of the papers is encouraged if the categorization of the paper is not clear. The categorization schemes themselves represent the different facets of the publications, which are established by screening through the papers starting with the abstract and continuing to the introduction and conclusion if needed. As the scheme is used during the mapping process, the scheme can evolve by adding new categories, and by merging or splitting existing categories. Visualizing the results by combining the different categories using a bubble plot can reveal the relative emphasis of the research on categories when mapped against each other. (Petersen et al., 2008.)

Existing classification schemes of research papers can be used to categorize the different facets of the papers (Petersen et al., 2008). Research types describe the general approach of the article to the subject matter instead of defining a specific method. The research types are based on the engineering cycle, which is a non-sequential list of activities performed while designing an artifact and proposing a new technique for a purpose. (Wieringa, Maiden, Mead & Rolland, 2006.) The research types are classified as Validation Research, Evaluation Research, Solution Proposal, Philosophical Papers, Opinion Papers and Experience Papers. These categories can be assigned easily and do not require detailed evaluation of each paper. Validation research implement novel techniques as experiments i.e. in a laboratory setting; Evaluation research conducts an evaluation on a technique and reports the consequences in terms of benefits and drawbacks; Solution proposals present the applicability and the benefits of a new or a significant extension of an existing technique; Philosophical papers structure existing things using a taxonomy of a conceptual framework; Opinion papers express the opinion of the authors on a technique, how things should have been done or whether it is good or bad; Experience papers explain the first-hand experience of the authors when implementing a technique in practice. (Petersen et al., 2008.)

The IEEE database is a well-known and analysed database for publications in the subject of software engineering (O'leary, 2008). The IEEE Xplore database uses a keyword taxonomy with a controlled vocabulary that is used to categorize bodies of text. The taxonomy is helpful in linking terms, suggesting related terms to researchers and aiding navigation. The preferred qualities of a taxonomy are uniform depth for depicting the appropriate level of detail, flexibility for change suggested by those who apply the taxonomy and constant monitoring for the usage of the taxonomy for underuse of terms, which can indicate needs for merging categories and overuse, which can indicate needs for splitting of categories. (Finelli, Borrego & Rasoulifar, 2015.) The top-level IEEE categories of the 2019 edition are depicted in Figure 3.

- Aerospace and electronic systems
- Antennas and propagation
- Broadcast technology
- Circuits and systems
- Communications technology
- Components, packaging, and manufacturing technology
- Computational and artificial intelligence
- Computers and information processing
- Consumer electronics
- Control systems
- Dielectrics and electrical insulation
- Education
- Electromagnetic compatibility and interference
- Electron devices
- Electronic design automation and methodology
- Engineering - general
- Engineering in medicine and biology
- Engineering management
- Geoscience and remote sensing
- IEEE organization
- Imaging
- Industrial electronics
- Industry applications
- Information theory
- Instrumentation and measurement
- Intelligent transportation systems
- Lasers and electrooptics
- Magnetics
- Materials, elements, and compounds
- Mathematics
- Microwave theory and techniques
- Nanotechnology
- Nuclear and plasma sciences
- Oceanic engineering and marine
- Power electronics
- Power engineering and energy
- Product safety engineering
- Professional communication
- Reliability
- Resonance
- Robotics and automation
- Science - general
- Sensors
- Signal processing
- Social implications of technology
- Solid state circuits
- Superconductivity
- Systems engineering and theory
- Systems, man, and cybernetics
- Ultrasonics, ferroelectrics, and frequency control
- Vehicular and wireless technologies

Figure 3. IEEE keyword Taxonomy (Institute of Electrical and Electronics Engineers, 2019).

The contribution facet of a study describes the kind of outcome the research provides. Research outcomes can be classified as Models, which represents the structure that describe reality; Theory, which is the construct of the cause and effect relationships in the problem area; Framework/method, which are the models that describe a system for knowledge management; Guidelines, which offer advice based on the research results; Lessons learned, which offer advice, recommendations or personal opinions; Tool, which is an technological artefact that is used to implement or support knowledge management. (Paternoster et al., 2014.)

3.2 Application of method

In this study the process of a mapping study in software engineering was followed with some modifications to the establishing of the classification scheme. The process also applied guidelines for a systematic literature review by adapting them to a mapping study. The first step of the research process was to define the main research question:

- What kind of research has been done on knowledge management frameworks in software engineering?

The objective of this research was to examine how research related to knowledge management frameworks have been presented in the literature. The categorization was done by reading the abstract and assigning it to the categories. If the category could not be categorized confidently from the abstract alone, the paper was studied until the research type was revealed. To answer the main research question, three assisting research questions were formed.

The first assisting research question (RQ1) was

- What types of papers are being published?

The first research question was answered by gathering the information on the publication years, authors' geographical locations, publication forums and the number of citations the papers have accumulated. The papers were also read and examined for the type of research that was conducted in them. The research types by Wieringa et al. (2006) were summarized by Petersen et al. (2008) which were used as concise rules used to categorize the papers. The descriptions of each classification are summarised in Table 1.

Table 1. Criteria for the type of paper (Petersen et al., 2008)

Category	**Description**
Validation Research	Novel techniques implemented as experiments in a laboratory setting.
Evaluation Research	Techniques are implemented in practice and the consequences are reported.
Solution Proposal	Solution to a problem is presented, either new or a significant extension of an existing technique.
Philosophical Papers	Looking at existing things by structuring them in a new conceptual framework or taxonomy
Opinion Papers	Writer's opinion on a subject, does not follow a research method.
Experience Paper	First-hand experience of applying a technique to practice.

The second assisting research question (RQ2) was

- What are the keywords covered by the knowledge management framework publications?

The second research question was answered by categorizing the keywords of the papers defined by the authors. The keywords were extracted from the database of IEEE and the existing taxonomy was used to present the data in a more high-level way by grouping the resulting keywords in their top-level categories. One article had no IEEE keywords assigned to it and it was omitted.

The third supplementary research question (RQ3) was

- What types of scientific contributions have the publications made?

The third research question was answered by examining the paper for the type of contribution the paper had made and assigning them to their categories of Frameworks, Guidelines, Lessons learned, Model, Theory and Tool. The categorization scheme as defined by Shaw (2003) was used to find the contribution facets. The concise rules that were used to classify the contribution facet of the papers is depicted in Table 2.

Table 2. Criteria for Contribution Facet

Contribution facet	Description
Model	The outcome of a conceptualizing process that describes reality
Theory	The construct of cause-and-effect relationships
Framework/methods	Models that describe a system for knowledge management
Guidelines	Advice based on the research results
Lessons learned	Recommendations or personal opinions
Tool	An artefact that is used to implement or support knowledge management

The papers were also examined for the type of framework that was discussed in each paper. The frameworks were categorized as Prescriptive, Descriptive, and Hybrid as defined by Rubenstein-Montano et al. (2001) and the papers that did not identify a specific framework were classified as such. The concise rules that were used to categorize the frameworks are presented in Table 3.

Table 3. Classification of Knowledge management frameworks

Framework type	Description
Prescriptive framework	The framework provides direction for the discussion that leads the formation of knowledge management activities
Descriptive framework	The framework characterizes and describes the activities needed for knowledge management
Hybrid framework	The framework describes knowledge management activities and provides guidance for the formation for knowledge management activities

The assisting research questions were used to aid establishing the classification scheme that could be iterated upon during the research process.

The database was selected to be the well-known and analysed database of Institute of Electrical and Electronics Engineers (IEEE). The search term of “knowledge management framework” was used to capture the largest number of results on the database. No limits were placed on the date of publication. The inclusion criterion was established to include all the papers to examine the full history of the subject in the database. The exclusion criteria established were articles that were not in English or not accessible in full text form.

The data extraction and classification process were done by reading through the papers starting by the abstract and continuing with conclusion and studying the rest of the paper in more detail if the classification was not confident. As the classification process completes, the results are cross tabulated to present an overview into the relationships between the different aspects of the studies. The resulting categorizations are compared to the existing results in the broader topics of knowledge management and software engineering where direct comparison is available.

4. Mapping results of the knowledge management frameworks

The mapping study was conducted by using the steps defined in Chapter 3 to determine what kind of research has been done on knowledge management frameworks in software engineering. In this section the results of the mapping process are presented, and the foundation is laid out to determine the different properties of the research done on knowledge management frameworks. Three of the following chapters are structured based on the assisting research questions and the present results of the mapping process. Chapter 4.1 depicts the types of papers being published, Chapter 4.2 depicts the keyword coverage and Chapter 4.3 examines the scientific contributions made by the papers. Chapter 4.4 is not based on a supplementary research question but instead it presents the cross-tabulated maps of the relationships between categories to identify focus areas and research gaps.

4.1 Types of papers published

To have a general overview of the research, multiple categorization schemes were used to find the traits of the research.

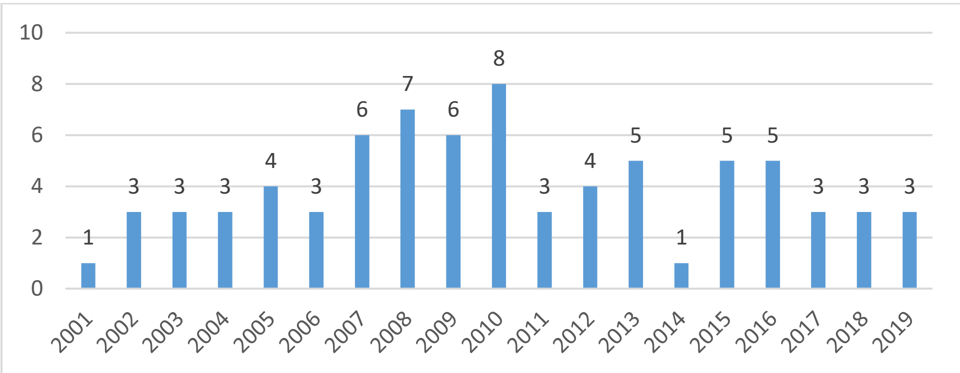

Figure 4. Distribution of the publications over time.

The temporal distribution of the publication dates is presented in Figure 4. The search in the database produced 76 papers in total, which were published between 2001 and 2019. The years with the largest number of papers published were the years between 2007 and 2010 with the 2010 year yielding most papers with 8 publications on the subject. The years that had the least number of publications were the year 2001 and 2014 with 1 paper published each year. Every year received at least one paper publication with the average of 4 papers published every year. The years 2007 to 2010 had an increase on the number of published articles with the average of 6,75 publications per year but otherwise the rate of publications on the subject each year have been steady with a temporary decrease in the year 2014.

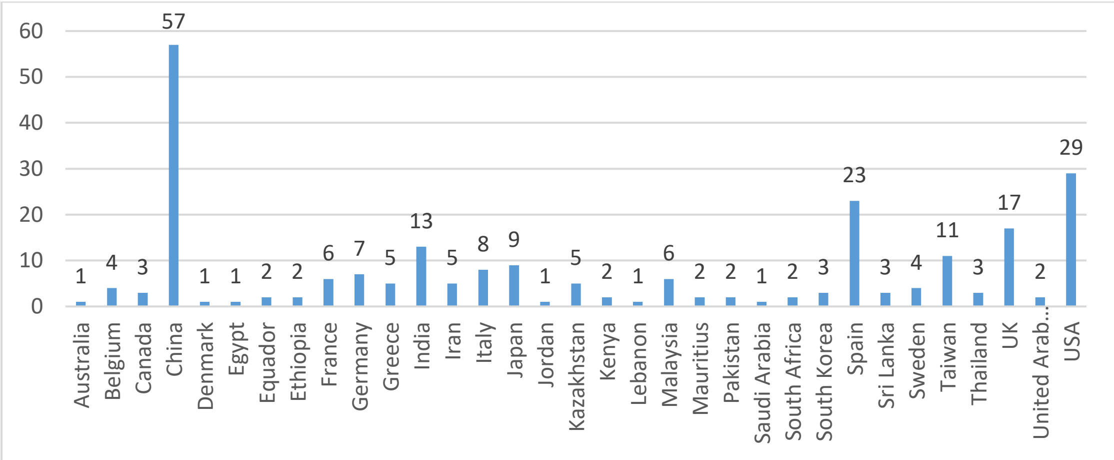

Figure 5. Distribution of the Geographic locations of the authors.

Figure 5 shows the geographical locations of the researchers. There were 241 researchers participating in the research in 33 countries. The largest represented countries were China (57 researchers), USA (29 researchers), Spain (23 researchers), United Kingdom (17 researchers) and India (13 researchers). The publications had an average of 3,4 authors per geographical location overall.

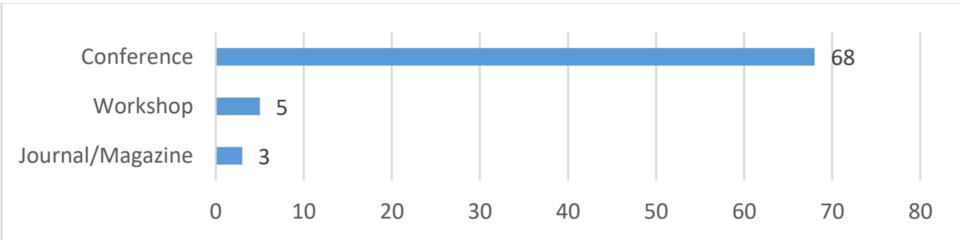

Figure 6. Distribution of publishing platform.

The studies were categorized by their publication forum type to conferences, workshop and the combination of scientific journals and magazines. The distribution of the categories is depicted in Figure 6. Out of the 76 total papers, 68 (89%) were published in conferences, 5 (7%) were a result of a workshop and 3 (4%) were published in a Journal or a Magazine.

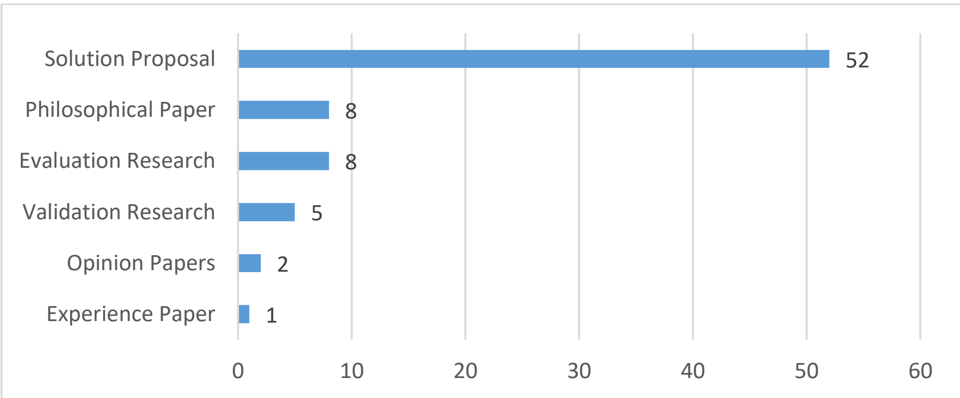

Figure 7. Distribution of research type.

The papers were assigned into the categories by their research type to examine the different types of approaches to the subject. The largest category was Solution Proposal with 52 publications (68,4%), followed by Philosophical Papers with 8 publications (10,5%), Evaluation Research with 8 publications (10,5%), Validation Research with 5 publications (6,6%), Opinion Papers with 2 publications (2,6%) and Experience Papers with 1 publication (1,3%). The distribution of the papers is depicted in Figure 7.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Solution Proposal	0	3	3	3	3	2	5	7	5	5	2	1	2	1	3	3	2	0	2
Philosophical Paper	1	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	1	2	0
Evaluation Research	0	0	0	0	0	0	0	0	0	1	0	1	3	0	1	1	0	1	0
Validation Research	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	1
Opinion Paper	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
Experience Paper	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 8. Temporal distribution of the research type.

The temporal distribution of the research types is presented in Figure 8. The solution proposal category had the most consistent publication rate with an average of 2,73 papers per year overall. The publication rates of the other categories across the time period were smaller by Philosophical papers with 0,42, Evaluation research with 0,42, Validation Research with 0,26, Opinion Papers with 0,10 and Experience Papers with 0,05. Solution Proposal had an increase in the publication rate during the years 2007 to 2010, when the average publication rate was 6,75 across that time period for the category as opposed to an average of 4 papers published every year overall. The other categories had less activity and typically had multiple years between single publications.

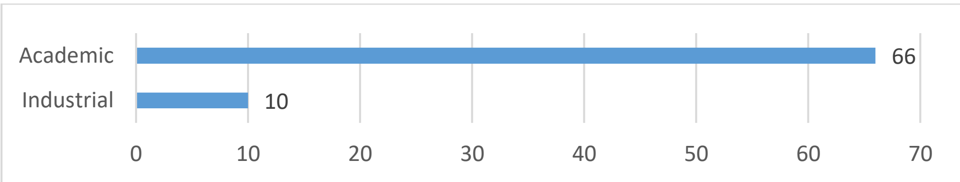

Figure 9. Distribution of the research context.

The context in which the research was performed were classified either to be Academic or Industrial as shown in Figure 9. The largest category was the research conducted in an academic context with 66 papers (87%) while the industrial category had 10 papers (13%).

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Academic	1	1	2	3	4	2	5	6	6	7	3	4	3	1	4	5	3	3	3
Industrial	0	2	1	0	0	1	1	1	0	1	0	0	1	0	0	0	0	0	0

Figure 10. Temporal distribution of the research context.

The temporal distribution of the research context is depicted in Figure 10. The academic papers are being published each year with an average of 3,5 publications per year as opposed to the industrial papers with the publication rate of 0,4 overall. Industrial context had one publication most of the years until 2014 when they stopped until the rest of the time period.

The papers were cited in total 154 times, ranging from 26 to 0 citations with the average of 2 citations per paper. There were 41 papers (54%) that had one or more citations out of the total of 76.

4.2 Keyword coverage

The keyword coverage was determined by keywords assigned by the authors using the IEEE taxonomy. The top-level categories of the IEEE taxonomy are used to display the results in a high-level manner.

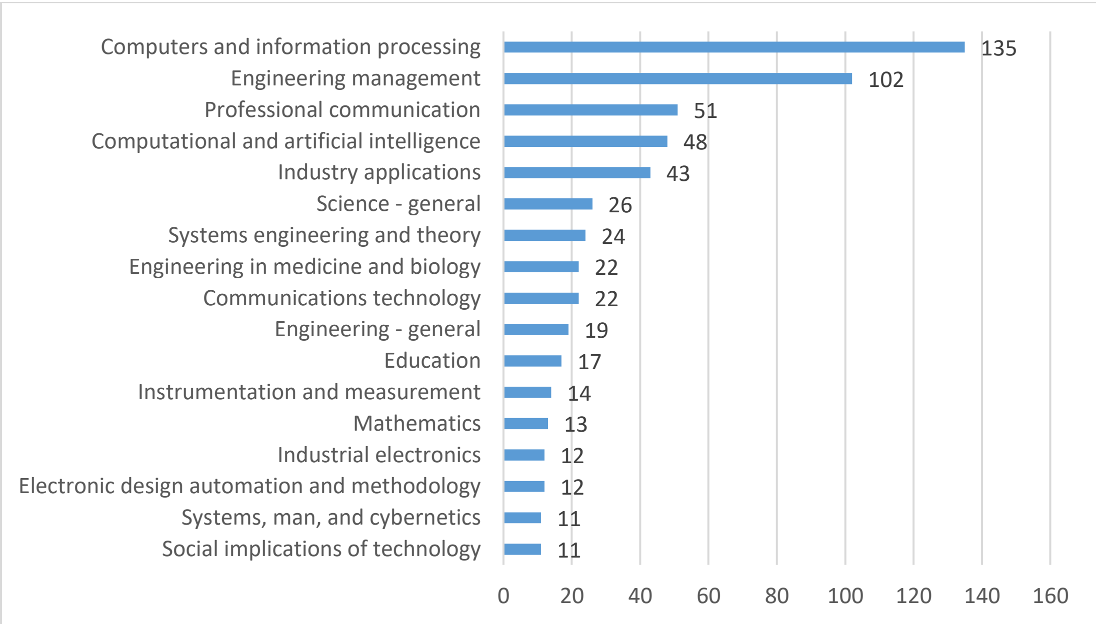

Figure 11. Distribution of the Top-level IEEE keywords categories of the 2019 IEEE taxonomy.

Grouping all the keywords from the papers into the top-level categories of the IEEE keyword taxonomy gives an overall view of the topics covered. The top-level categories that had 10 or more appearances are depicted in Figure 11. Out of the 51 total categories in the IEEE keyword list, 35 were covered by at least one keyword. The largest categories covered were Computers and information processing with 135 papers, followed by Engineering management with 102 papers, Professional communication with 51 papers, Computational and artificial intelligence with 48 papers and industry applications 43 papers.

The temporal distribution of all the top-level keyword appearances is depicted in Figure 12. There was a rise in keyword appearances during the years 2007-2010 when the rate of publications was higher but overall, the keyword coverage is consistently low but diverse.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Aerospace and electronic systems	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Circuits and systems	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
Communications technology	0	1	1	0	0	0	4	1	1	2	0	2	5	0	3	0	0	0	2
Computational and artificial intelligence	0	3	5	6	2	1	5	5	6	4	0	0	2	0	2	4	2	0	1
Computers and information processing	1	6	5	4	11	7	17	14	9	12	6	6	5	2	7	9	6	3	4
Consumer electronics	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Education	0	0	2	0	2	0	2	6	1	1	1	1	0	0	0	0	0	0	1
Electromagnetic compatibility and interference	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1
Electronic design automation and methodology	0	1	2	2	0	0	1	2	0	3	0	0	1	0	0	0	0	0	0
Engineering - general	0	1	0	2	3	2	0	2	3	6	0	0	0	0	0	0	0	0	0
Engineering in medicine and biology	0	2	3	0	6	0	0	4	0	1	0	0	4	0	0	2	0	0	0
Engineering management	8	4	4	0	6	5	6	11	21	11	3	2	4	1	3	7	4	1	1
Geoscience and remote sensing	0	0	0	0	0	0	1	1	1	0	0	0	0	2	0	0	0	0	0
IEEE organization	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Imaging	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Industrial electronics	0	0	0	2	0	0	5	1	0	0	0	0	2	0	1	0	0	0	0
Industry applications	0	4	2	4	3	1	0	6	7	6	1	1	0	1	3	0	2	0	2
Information theory	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1
Instrumentation and measurement	0	2	0	1	1	0	1	1	0	0	0	2	1	1	2	0	0	1	1
Intelligent transportation systems	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2	0	0	0	0
Lasers and electrooptics	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Materials, elements, and compounds	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0	0
Mathematics	0	0	1	1	0	0	2	1	1	2	0	0	0	0	1	1	1	0	2
Power engineering and energy	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0
Product safety engineering	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Professional communication	0	5	1	5	1	4	7	3	4	8	3	2	4	0	1	1	1	1	0
Reliability	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0
Robotics and automation	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Science - general	0	0	1	1	1	2	5	3	2	3	0	1	2	1	1	1	1	1	0
Sensors	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1
Signal processing	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0
Social implications of technology	0	0	0	0	0	1	1	1	2	2	1	0	0	0	2	0	0	1	0
Systems engineering and theory	0	2	1	0	0	2	3	0	1	6	0	2	0	0	1	0	1	2	2
Systems, man, and cybernetics	0	0	2	0	1	2	1	1	0	2	1	0	0	0	0	0	0	0	1
Ultrasonics, ferroelectrics, and frequency control	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 12. Temporal distribution of the Top-level IEEE keyword categories.

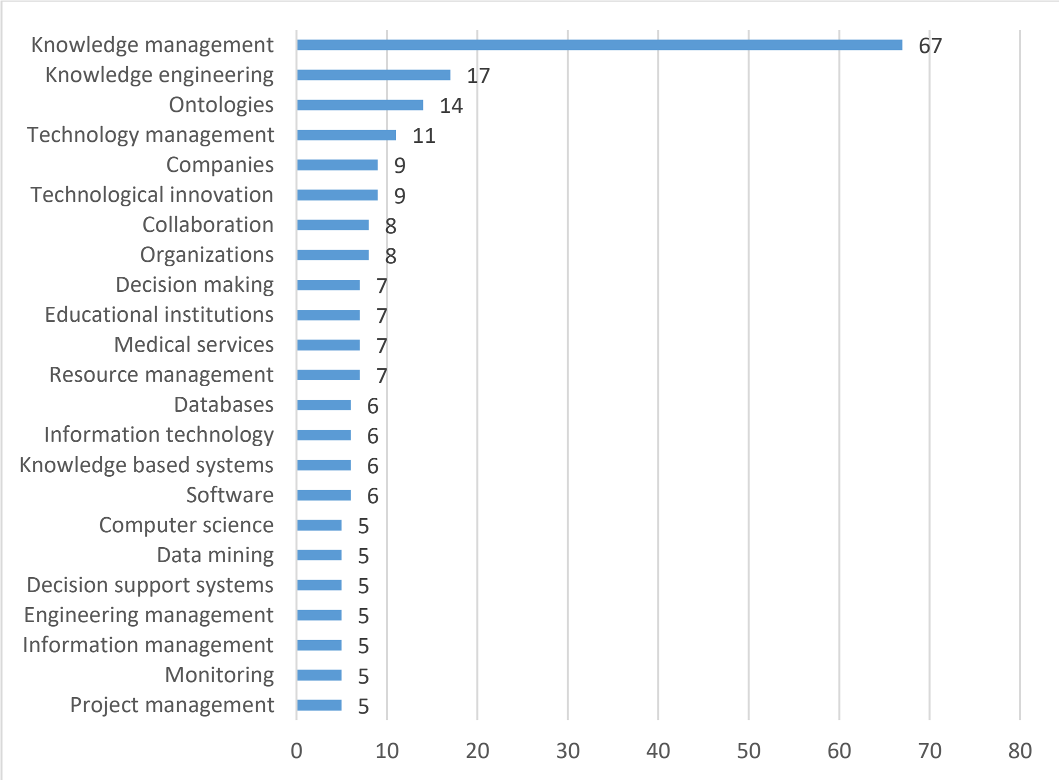

Figure 13. Keywords of the IEEE taxonomy used by the papers.

The single keywords used by the authors are used to depict the keyword usage in a more granular manner. The keywords chosen by the authors that had 5 or more appearances are shown in Figure 13. Out of the 76 papers, "Knowledge management" is the most used keyword with 67 appearances, followed by "Knowledge engineering" (17), "Ontologies" (14) and "Technology management" (11). The other keywords had less than 5 appearances. The full list of the keywords used by the papers is available in Appendix B.

4.3 Types of scientific contributions

The scientific contributions were classified by the contribution facet and the framework they examined in the work.

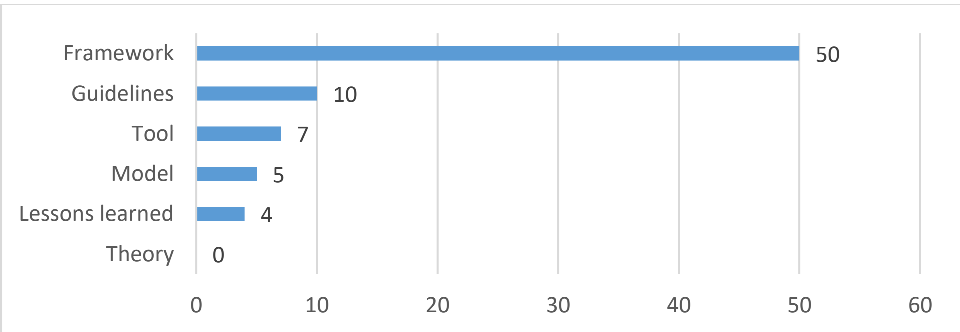

Figure 14. Distribution of contribution facets.

The papers were classified by their contribution facet into the six categories as depicted in Figure 14. The Framework category was the largest with had 50 papers (66%), Guidelines with 10 papers (13%), Tool with 7 papers (9%), Model with 5 papers (7%), Lessons learned with 4 papers (5%) and Theory with no papers (0%).

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Framework	0	2	3	2	1	2	3	6	4	6	2	3	2	1	4	4	2	2	1
Guidelines	1	0	0	0	2	0	1	1	1	0	0	0	0	0	0	1	1	1	1
Tool	0	0	0	0	1	0	1	0	0	0	0	1	3	0	0	0	0	0	1
Model	0	1	0	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0
Lessons learned	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0
Theory	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 15. Temporal distribution of the contribution facets.

The temporal distribution of the contribution facet presented in the papers is depicted in Figure 15. The Framework category is well represented across all the years with an average of 2,63 papers publications per year with a peak during the years 2008 and 2010 with 16 publications and an average of 5,33 per year during that time period. The publication rates of the smaller categories during the time period were Guidelines with 0,53, Tool with 0,37, Model with 0,26, Lessons learned with 0,21 and Theory with 0.

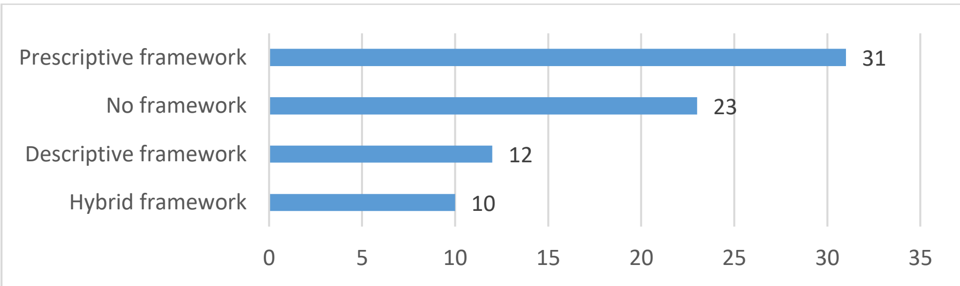

Figure 16. Distribution of framework types.

The papers were classified into categories by the nature of the framework examined in the paper as depicted in Figure 16. There were 31 papers with Prescriptive frameworks (41%), 23 papers did not have a specific knowledge management framework in them (30%), 12 papers with descriptive frameworks (16%) and 10 papers with hybrid frameworks (13%). This shows a focus on prescriptive frameworks compared to descriptive and hybrid frameworks. Papers not discussing a particular framework were also well represented, being the second largest category.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Prescriptive framework	0	1	3	2	1	1	2	4	3	3	2	1	0	0	3	3	1	0	1
Descriptive framework	0	0	0	0	0	1	1	1	2	3	0	1	2	0	0	0	0	1	0
Hybrid framework	0	1	0	0	0	0	0	1	0	1	0	2	0	1	1	1	1	1	0
No framework	1	1	0	1	3	1	3	1	1	1	1	0	3	0	1	1	1	1	2

Figure 17. Temporal distribution of framework types.

The temporal distribution of the framework type in publications is depicted in Figure 17. Publications have been consistent with some multi-year gaps during the time period.

4.4 Relationships between categories

The maps of the relationships between the categories are presented as a bubble plots to examine the relationships between them. The categories are used as the two axes and the value and the size of the circle indicate how many articles are found in each cross section. The different properties of the research efforts examined together is used to identify the focus areas and research gaps.

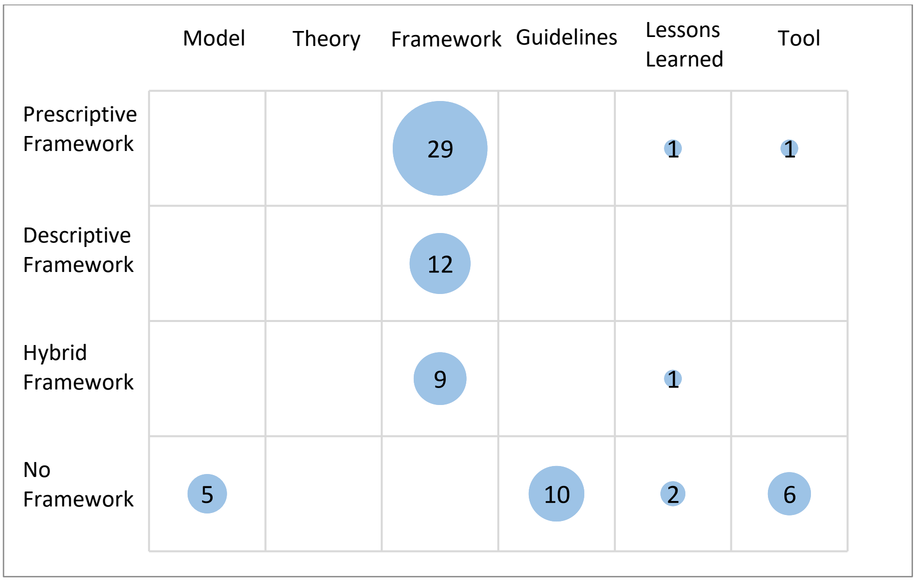

Figure 18. Map of framework types and research outcomes.

The map of the relationships between the framework types and research outcomes is presented in Figure 18. The resulting map depicts two distinct themes from the papers, the larger being framework descriptions distributed over the different types of frameworks and the other being examination of the issues surrounding the different frameworks themselves.

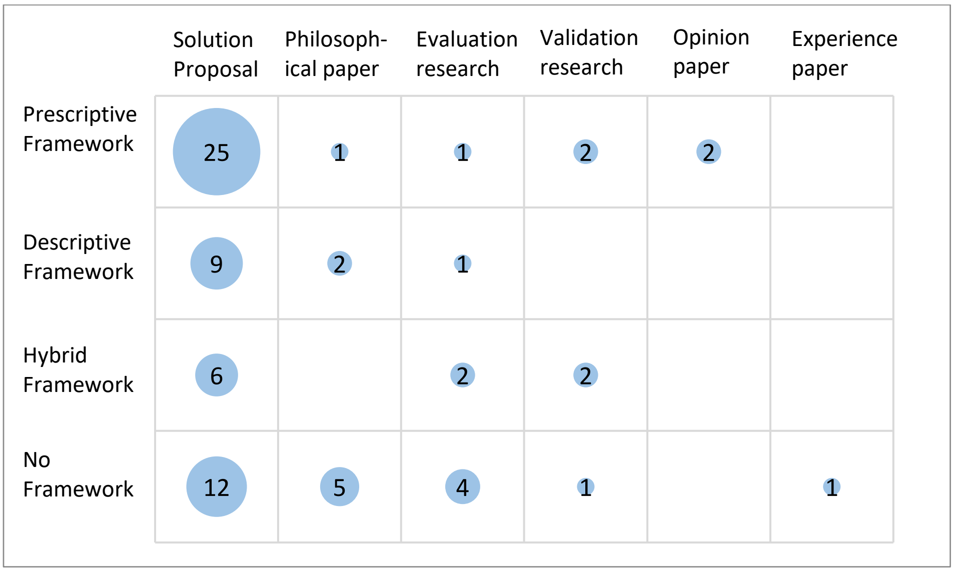

Figure 19. Map of framework types and research types.

The relationships between research types and framework types are presented in Figure 19. Solution Proposal is the largest category with multiple papers in all categories. The other categories have smaller amounts of research in each cross section, depicting a lack of coverage. Opinion papers and Experience papers lacked the most in coverage by only having articles in single categories. The Opinion papers had 2 papers in Prescriptive frameworks and Experience paper had one paper not focusing on a particular framework.

5. Discussion

The objective of the study was to examine the efforts on knowledge management frameworks by using a mapping study as the research method. The main research problem was to find out properties of research regarding knowledge management frameworks in software engineering. In this section, the research questions are answered by discussing the results of the study and comparing them to existing literature to offer insights into the subject and draw implications from theoretical and practical perspectives. Chapter 5.1 answers the research questions by combining and interpreting the results of the mapping process. Chapter 5.2 presents the theoretical and empirical implications of the research. Chapter 5.3 comments on the methodological considerations and limitations that became apparent during the research process.

5.1 Answers to the research questions

The main research question was about what kind of research has been done on knowledge management frameworks in software engineering, which was divided into three assisting research questions.

RQ1: What types of papers are being published?

The 76 papers that resulted from the search have been published across all the years with an average of 4 papers per year. The years with most of the publications were the years from 2007 to 2010 when the average was 6,75. The papers have been cited in total 167 times within the IEEE database, with an average of 2,2 citations per article. The papers were being mostly published in conferences with 89% of the publications in that category and a smaller number of papers were published in workshops (7%) and journals and magazines (4%). In prior research by Souza et al. (2014) there was no clear preference on the publication forum, but an emphasis on the publications made in conferences. In this study the conferences were clearly preferred as the publication forum. The largest portion of the geographical location of the researchers was China with 24%, followed by USA with 12%. This is in contrast compared to the prior research by Wang et al (2018) who found that the country that had the largest amount of participation in the knowledge management field research was United States of America with 25% of the papers.

A large portion of the research type was focused on Solution proposals (68,4%) in the form of presenting different frameworks to use in a specific context. The categories related to the usage of frameworks and examining them have been published in all categories of Philosophical papers (10,5%), Evaluation research (10,5%), Validation research (6,6%), Opinion papers (2,6%) and Experience papers (1,3%). In prior research on software engineering in start-ups, the largest category of the primary studies was evaluation research (49%) followed by experience papers (21%) and solution proposals (16%) (Paternoster et al., 2014). These previous findings differed from this study in that most of the papers in the context of knowledge management frameworks consisted of solution proposals. The results of this paper are in line with the findings by Engström & Runeson (2010) in the context of Software product line testing, having the Solution proposal as the largest category.

RQ2: What are the keywords covered by the knowledge management framework research?

There were 302 unique keywords covered by the research on knowledge management frameworks. The most covered keywords by knowledge management research were “Knowledge management” (67), “knowledge engineering” (17), “ontologies” (14), “technology management” (11), “companies” (9), and “technological innovation” (9). In prior research by Wang et al. (2018) the most used keywords were “knowledge sharing”, “innovation”, “ontology” and “knowledge management”. Similar popular keywords found in this study were “technological innovation”, “ontologies”, and “knowledge management”. The second most used keyword in the prior literature, “Knowledge sharing” did not appear in the taxonomy and was replaced by “knowledge engineering” in the rankings. In general, the keywords usage in this study was similar to prior research but the overall keyword set has been more technically oriented as opposed to the keywords in previous studies have been focused on the general concepts of knowledge management.

RQ3: What types of scientific contributions have the publications made?

The contributions made were mostly frameworks with 66% of the papers belonging to that category. The categories Guidelines, Tools, Models, and Lessons learned had smaller portions of the papers. No papers in the theory category were found. The categories show that the 28% of the contributions are of the weak type (Guidelines, Tools, Lessons learned) and the remaining 72% are of the strong type (Theory, Framework, Models). It is noteworthy that the contribution type of the frameworks consists mostly of the strong type of contributions, with theories and models being the smaller portion. This shows that most of the papers discuss a certain framework whereas the remaining portion of the papers discuss the issues related to knowledge management frameworks. In prior research, most of the contributions on the field of knowledge management have been of the weak type (Paternoster et al., 2014). In their research 63% of the research contributions belonged to the weak type and 37% to the strong type. Compared to this study the results have yielded different results, which could be explained by the focus of this study being on the frameworks specifically, which are the artefacts that are results of a process of modelling the knowledge flow in an organization.

All the knowledge management framework types are being researched with prescriptive frameworks being most discussed (40%). The second largest category of frameworks discussed are descriptive frameworks (15%) and hybrid frameworks (13%) being the least studied. There were 23 (30%) out of the 76 total of papers that did not discuss a particular framework but rather the issues related to knowledge management frameworks.

5.2 Implications

Overall, the results of this mapping study are novel as the specific topic of knowledge management frameworks has no mapping studies conducted on it. The results were compared to prior mapping studies that examined knowledge management or software engineering. There have been consistent publications over the 19 years of the material with 76 publications, which have been cited in total 167 times within the IEEE database, which makes an average 2,2 citations per article. The research field of knowledge management started to become popular after the year 2000 (Wang et al., 2018), which corresponds to the start of the appearance of the articles published in the selected database.

The research is not balanced across every type of study, as the studies are focused in fewer key areas, with proposed frameworks being the largest one. This shows that there is a larger proportion of frameworks that have not been evaluated and validated. To achieve more balanced effort on the research on knowledge management frameworks, the existing frameworks need examination in the form of evaluation and validation. Sunassee & Sewry (2002) recommended that knowledge management frameworks should have both prescriptive and descriptive elements to them. Only 10 out of the 53 frameworks presented in the literature were categorized as hybrid frameworks, having both elements to them. There has been limited work on examining the types of framework being proposed and there has been no recent publications of mapping studies or literature reviews. According to Rubenstein-Montano et al. (2001), the most common frameworks being published are prescriptive, which makes the results of this study in line with this prior knowledge.

The results of this study can be used by organizations considering launching an initiative for the introduction of a knowledge management framework. This study provides an overview on the research that is performed and gives indications about the areas of research interest and possible success factors that affect the undertaking. In an academic context, the areas of interest identified by the results of the mapping process could be further examined by a systematic literature review.

5.3 Methodological considerations and limitations

At the beginning of the research process, fewer research questions and categorization schemes were established, but as the study went on, more categories were found to be useful as the understanding of the subject matter grew. The development of the classification schema was accomplished by defining and iterating on additional secondary research questions and categorization schemes that aid answering those questions. This made the research take an exploratory approach to developing the assisting research questions and the categorization schemas that are used to answer them. The categorization schemas required varying degrees of iteration to mirror the requirements set by the assisting research questions.

During the research process it became apparent that a more detailed analysis of each paper was required to answer the research questions, which enabled iteration on the schema and the categorization method. An adaptive reading depth as suggested by Petersen et al. (2008) was necessary to confidently assign the papers to the categories. The accuracy of the mapping depends much on the interpretation of the terms used by existing categories and the possible overlapping of two categories. As the material is mapped, judgment calls are made on the material, which steers the research method to a hybrid of qualitative and quantitative depending on the research question. This affected the research process by demanding varying reading depth with each paper as the clarity of the classifications of the papers varied.

The predefined keywords that used the IEEE taxonomy were selected to represent the broader areas of interest by using the topmost layer of the taxonomy. During the keyword process it was found that some IEEE keywords used by the articles were not available in the 2019 version of the taxonomy. There were differences between the 2019 version and the one that was used to originally classify the article. The outlying keywords were manually assigned to the corresponding top-level keywords to the best of the authors knowledge. There were multiple sets of keywords available in the IEEE database. Authors are instructed to use 3-10 keywords per article, and there can be differing methods of choosing them, such as leaving out keywords that exist already in the title or the abstract of the paper. Using the other sets of keywords or manually creating a taxonomy could have been used to give insight to the keyword selection from a point of view other than the taxonomy used by IEEE.

6. Conclusion

In this study, knowledge management frameworks in software engineering were examined by using the research method of mapping study to present an overview into the research done in the field. This study has resulted in an overview of the studies published by IEEE, which enabled examining the efforts of technically oriented organizations on knowledge management frameworks. The chosen database yielded 76 papers, which were used as the material for the mapping study.

The goal of the study was to get an overview into the efforts on knowledge management frameworks research in the field of software engineering. The goal was formed into a research question of 'what kind of research has been done on knowledge management frameworks in software engineering'. This was answered by dividing the main research question into three assisting research questions that answered what kind of papers are being published, what keywords are being covered and what type of scientific contributions have been made.

The main result of this study was identifying the different properties and focus areas of the research performed on knowledge management frameworks in software engineering. The largest focus over the years has been on propositions of various frameworks as solutions to different organizational contexts. The maps that resulted from the research process show that there is more focus on proposing frameworks and describing them rather than examining existing frameworks and evaluating their performance.

This material used in this study was limited to the papers published by IEEE, which make the results represent only the efforts of engineering background and do not necessarily reflect of the state of the efforts on knowledge management frameworks in a larger context. During the research it became apparent that the abstracts of the papers were not enough for confident classification, and all of them had to be studied more closely with varying depth to be able to extract the information relevant to answering the research questions. Most of the papers published were descriptions of different types of frameworks that have not been evaluated or validated separately. Publication bias might also be relevant, which is the reporting of only successful implementations of knowledge management framework initiatives. The IEEE keyword taxonomy has been updated over the years and there are differences between the yearly editions, which makes it possible that the older papers have been assigned into a category that has been merged to another category or does not exist anymore. This discrepancy might result in keywords being mapped into the wrong category. The usage of the IEEE keyword taxonomy and its limitations is a threat to the validity of the results of the keyword mapping process because they are chosen by the authors who might be affected by the restrictions of the taxonomy, their own keyword selection method and the maximum number of keywords allowed.

The overview into the subject matter provided by this study, could be applied in the future to wider material with similar research questions expanded to more databases to accomplish a broader look into the field. A systematic mapping study would be necessary to identify main studies, give wider insight into the field and facilitate a systematic literature review. The interest and relevance of knowledge management frameworks might also be interesting to investigate in the field of knowledge management.

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Appendix A: Mapping study data

Year	Article name	Authors	Citations	Published in	Research type	Framework type	Contribution facet	Organizational context
2001	Knowledge Management as a Framework for understanding public sector outsourcing	G. Beyah; M. Gallivan	7	Conference	Philosophical paper	No Framework	Guidelines	Academic
2002	A Distributed Knowledge Model for Collaborative Engineering Knowledge Management in Allied Concurrent Engineering	Chin-Bin Wang; Yuh-Min Chen; Yuh-Zen Chen	2	Conference	Solution proposal	No Framework	Model	Academic
2002	The research and design of the knowledge management framework - a case study of MXIC OTRB/IE community	C. C. Feng; Mico Peng; Henry Hsiao; Simon Jou; Mike Lin	0	Conference	Solution proposal	Prescriptive framework	Framework	Industrial
2002	Towards a holistic Knowledge Management Framework for Healthcare Institutions	A. Dwivedi; R. K. Bali; A. E. James; R. N. G. Naguib; D. Johnston	2	Conference	Solution proposal	Hybrid framework	Framework	Industrial
2003	ConKMeL: a contextual knowledge management framework to support intelligent multimedia e-learning	W. Huang; M. O'Dea; A. Mille	2	Conference	Solution proposal	Prescriptive framework	Framework	Industrial
2003	Ontology-based Reconfigurable Case-based Reasoning System for Knowledge Integration	Yinglin Wang; Tao Hu; Shensheng Zhang	8	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2003	Organization current knowledge design (OCKD): a knowledge management framework for healthcare institutions	A. N. Dwivedi; R. K. Bali; R. N. G. Naguib	9	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2004	A Distributed Knowledge Network for Real World Robot Applications	Nak Young Chong; H. Hongu; K. Ohba; S. Hirai; K. Tanie	26	Conference	Solution proposal	No Framework	Model	Academic
2004	Knowledge Management Framework to Share Technical Know-How in Organization	Y. Horiguchi; T. Sawaragi; Y. Kaneda; A. Nakajima	1	Conference	Solution proposal	Prescriptive framework	Framework	Academic

2004	On technology for engineering knowledge refinement	Yuh-Min Chen; Yuh-Jen Chen; Ching-Bin Wang	0	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2005	An Adaptive Middleware to Support Context-Aware Knowledge Sharing	R. Boselli; F. Cabitza; F. De Paoli; M. Loregian	2	Conference	Solution proposal	No Framework	Tool	Academic
2005	Interoperability of Data and Knowledge in Distributed Health care Systems	R. S. Kazemzadeh; K. Sartipi	5	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2005	Requirements for a knowledge management framework to be used in software intensive organizations	P. Martinez; A. Amescua; J. Garcia; D. Cuadra; J. Llorens; J. M. Fuentes; D. Martin; G. Cuevas; J. A. Calvo-Manzano; T. S. Feliu	4	Conference	Experience paper	No Framework	Guidelines	Academic
2005	Towards Knowledge Morphing: A Triangulation Approach to Link Tacit and Explicit Knowledge	F. Hussain; S. S. R. Abidi; S. A. Raza	0	Conference	Solution proposal	No Framework	Guidelines	Academic
2006	Acquiring Innovative Knowledge via Effective Process Management	W. Huang	3	Conference	Solution proposal	No Framework	Model	Academic
2006	Automating Command Post and Battle Staff Operations at the USAF 45th Space Wing	R. D. Price; T. W. Beltz; N. McKinnon	0	Conference	Opinion paper	Prescriptive framework	Framework	Industrial
2006	Knowledge Management Framework for Ubiquitous Systems	M. Rafi; Y. Lee; S. Lee	0	Conference	Solution proposal	Descriptive framework	Framework	Academic
2007	Classification and Ontology Maintenance in Agent-Based Knowledge Management Frameworks: A Prototypical Approach	C. Falge; R. Cobos; G. Groh	1	Conference	Solution proposal	No Framework	Tool	Academic
2007	Construction of a Knowledge Management Framework Based on Web 2.0	L. Wan; C. Zhao	1	Conference	Solution proposal	Descriptive framework	Framework	Academic
2007	DOKMF: Distributed Ontology-Based Knowledge Management Framework	G. Wang; L. Yang	1	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2007	Knowledge Management Approach in Mobile Software System Testing	Ong Kein Wei; Tang Mei Ying	0	Conference	Solution proposal	No Framework	Guidelines	Industrial
2007	Re-conceptualizing the digital divide: a knowledge-based approach	W. Tibben	3	Conference	Philosophical paper	No Framework	Model	Academic

2007	Research on Knowledge Management Framework Based on Peer-to-peer Computing	W. Yang; M. Zhao	1	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2008	A Framework of Knowledge Management for Mass Customization Internet-based	T. Luo; Z. Xiong; Y. Fang	1	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2008	A Knowledge Management Framework for Software Configuration Management	N. Ploskas; M. Berger; J. Zhang; G. Wintterle	1	Conference	Solution proposal	Prescriptive framework	Framework	Industrial
2008	Distributed Knowledge Management Based on Extended Topic Maps	H. Lu; B. Feng; Y. Zhao; Q. Zheng; J. Liu	5	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2008	Distributed knowledge management for collaborative design	Junming Hou; Chong Su; Shuang Lang; Yingying Su; Wanshan Wang	1	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2008	Knowledge Management Framework for Improving Curriculum Development Processes in Technical Education	S. Agrawal; P. B. Sharma; M. Kumar	5	Conference	Solution proposal	Hybrid framework	Framework	Academic
2008	Research on the overall framework of knowledge management	Y. Wu; J. Pang	2	Conference	Solution proposal	Descriptive framework	Framework	Academic
2008	Towards a knowledge management framework for assisting organisations to evaluate their own (non-clinical) approaches to the dissemination of knowledge about HIV/AIDS intervention programmes in South Africa	R. Sassman; B. Lehaney; I. Marshall	0	Conference	Solution proposal	No Framework	Guidelines	Academic
2009	Research on Knowledge Management Based on the Scheduling Flow of Water Resources	D. Huang; C. Zhang; L. Wang; J. Yang	0	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2009	Research on Knowledge Management Framework in R & D Organization	Z. Hao; H. Liu	0	Conference	Solution proposal	Descriptive framework	Framework	Academic
2009	Study on Knowledge Management of Water Running Scheduling	D. Huang; C. Zhang; H. Zhang	0	Conference	Solution proposal	Prescriptive framework	Framework	Academic

2009	Study on the Framing of Knowledge Management for College Library Management	Z. Yang; S. Liu	0	Conference	Solution proposal	Descriptive framework	Framework	Academic
2009	The Knowledge Management Frame Construction Research in Collaborative Supply Chain	S. T. Zhang; D. Q. Zhang; S. L. Kuang; L. B. Huang	0	Conference	Solution proposal	No Framework	Guidelines	Academic
2009	Towards Effective Enterprise Knowledge Management Through Fuzzy Semantics	P. Alexopoulos; M. Wallace; K. Kafentzis; D. Askounis	0	Conference	Validation research	Prescriptive framework	Lessons learned	Academic
2010	A Framework for Ontology-based Product Design Knowledge Management	D. Zhang; D. Hu; Y. Xu	4	Conference	Solution proposal	Descriptive framework	Framework	Academic
2010	An Approach to Overcoming Knowledge Sharing Challenges in a Corporate IT Environment	S. B. Lee; S. G. Shiva	0	Conference	Evaluation research	No Framework	Lessons learned	Academic
2010	Developing a Knowledge Management framework based on Km cycle in non-profit educational centers: A multi case analysis	P. Akhavan; R. Hosnavi	1	Conference	Validation research	Hybrid framework	Lessons learned	Academic
2010	Facilitating Use of LCC by Knowledge Management: An Empirical Case Study	W. He; Y. Yin	0	Conference	Solution proposal	Descriptive framework	Framework	Academic
2010	Semantic Services for Intelligence Preparation of the Battlefield (IPB) Composition	T. Darr; P. Benjamin; R. Mayer; R. Fernandes; A. Jain	1	Conference	Philosophical paper	Prescriptive framework	Framework	Academic
2010	Study on engineering knowledge management in collaborative product design	L. J. Yan; Z. B. Li; X. Y. Yuan	0	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2010	The Method of Manufacturing Knowledge Management Based on Manufacturing Resource Capacity	P. Wang; X. Tian; J. Geng; F. H. Key	1	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2010	User-centered Systems Engineering Approach to Design and Modeling of Smarter Products	T. Z. Ahram; W. Karwowski; B. Amaba	7	Conference	Solution proposal	Descriptive framework	Framework	Industrial

2011	A Conceptual Knowledge Management Framework in Consultancy Services	N. A. B. M. Farid; M. S. Ahmad	0	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2011	A Knowledge Management Framework for Agile Software Development Teams	R. K. Kavitha; M. S. Irfan Ahmed	7	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2011	A Research on the Mechanism of action of the Knowledge Management to the Core Competitiveness in Publishing Enterprises	Z. Tuo; H. Cong; C. Gao	0	Conference	Philosophical paper	No Framework	Lessons learned	Academic
2012	A Holistic Knowledge Management Framework for Higher Education Institutions	R. Kumar; K. Sarukesi; G. V. Uma	1	Conference	Philosophical paper	Descriptive framework	Framework	Academic
2012	Embedding knowledge in HR processes	K. M. Succendran; R. Saravanan; K. Sarukesi	0	Conference	Evaluation research	Hybrid framework	Framework	Academic
2012	Framework for Knowledge Management in Engineering Institute	N. Puttappa; P. Siddaiah	0	Conference	Solution proposal	Hybrid framework	Framework	Academic
2012	Velo: A Knowledge-Management Framework for Modeling and Simulation	I. Gorton; C. Sivaramakrishnan; G. Black; S. White; S. Purohit; C. Lansing; M. Madison; K. Schuchardt; Y. Liu	14	Journal/Magazine	Opinion paper	Prescriptive framework	Tool	Academic
2013	A Mobile Knowledge Management Framework for Police Force	Z. M. Jhingut; S. D. Nagowah	1	Conference	Evaluation research	Descriptive framework	Framework	Industrial
2013	Enhancing Knowledge Management Capabilities in Web-based Decision Aids using Fuzzy Prototypes and Data Quality Criteria	F. P. Romero; J. A. Olivas; I. Caballero; J. Serrano-Guerrero; M. J. Oruezabal	0	Conference	Solution proposal	No Framework	Tool	Academic
2013	Exploiting Knowledge Management for Supporting Multi-Band Spectrum Selection in Non-Stationary Environments	F. Bouali; O. Sallent; J. Perez-Romero; R. Agusti	5	Journal/Magazine	Evaluation research	No Framework	Tool	Academic
2013	Knowledge Management Framework for achieving Quality of Healthcare in the Developing Countries	J. L. Amararachchi; H. S. C. Perera; K. Pulasinghe	1	Conference	Solution proposal	Descriptive framework	Framework	Industrial

2013	Knowledge Management Framework for Robust Cognitive Radio Operation in Non-Stationary Environments	F. Bouali; O. Sallent; J. Pérez-Romero	0	Conference	Evaluation research	No Framework	Tool	Academic
2014	Developing high resolution remote sensing technology into an advanced knowledge management system to monitor and assess water resources	D. Kaskina; R. A. Bradshaw; A. James; Y. H. Kho; M. Kabiyeva	1	Conference	Solution proposal	Hybrid framework	Framework	Academic
2015	A knowledge management framework for manufacturing firms in South Africa	A. Fivaz; M. W. Pretorius	0	Conference	Solution proposal	Hybrid framework	Framework	Academic
2015	Event Extraction for Collective Knowledge in Multimedia Digital EcoSystem	M. A. Abebe; F. Getahun; S. Asres; R. Chbeir	0	Conference	Validation research	Prescriptive framework	Framework	Academic
2015	Knowledge Management Framework for Monitoring Systems improving Building Energy Efficiency	M. Kadolsky; R. Windisch; R. J. Scherer	0	Conference	Solution proposal	Prescriptive framework	Framework	Industrial
2015	Organizational Secure Knowledge Flow Model	M. G. Tajgardoon; M. T. M. Shalmani; J. Habibi	1	Conference	Evaluation research	No Framework	Model	Academic
2015	Towards Risk Knowledge Management in Unmanned Aerial Vehicles Applications Development	A. Idries; N. Mohamed	0	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2016	A Knowledge Management Framework for imbalanced data using Frequent Pattern Mining based on Bloom Filter	S. M. El-Ghamrawy	2	Conference	Evaluation research	Prescriptive framework	Framework	Academic
2016	A Knowledge Management Framework for Studying the Child Obesity	R. Suteeca; P. Sugunnasil	0	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2016	A Proposed Knowledge Management Framework for Boosting the Success of Information Systems Projects	A. A. Alawneh; R. Aouf	0	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2016	Datawarehouse design for Educational Data Mining	O. Moscoso-Zea; Andres-Sampedro; S. Luján-Mora	8	Conference	Solution proposal	No Framework	Guidelines	Academic
2016	Knowledge Management Framework for Software Reuse	S. Maccanti; J. Al-Jaroodi; A. Sirinterlikci	4	Conference	Validation research	Hybrid framework	Framework	Academic

2017	A Goal-Driven Framework in Support of Knowledge Management	G. Rong; X. Liu; S. Gu; D. Shao	0	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2017	Knowledge sharing among engineers: An empirical examination	O. E. Contreras-Pacheco; C. Claasen; R. Nishant	1	Conference	Philosophical paper	No Framework	Guidelines	Academic
2017	Quality Requirements in Agile as a Knowledge Management Problem: More than Just-in-Time	E. Knauss; G. Liebel; K. Schneider; J. Horkoff; R. Kasauli	1	Conference	Solution proposal	Hybrid framework	Framework	Academic
2018	Conceptualization of a Knowledge Management Framework for Governments: A case of Devolved County Governments in Kenya	P. K. Wamuyu; J. R. Ndiege	0	Conference	Philosophical paper	Descriptive framework	Framework	Academic
2018	Knowledge Management Framework for Sustainable Development: A Case Study of a Research Group in a University	S. Nupap	0	Conference	Evaluation research	Hybrid framework	Framework	Academic
2018	Social Presence in Digital Community	S. Ismail; S. H. Shaikh Ali	0	Conference	Philosophical paper	No Framework	Guidelines	Academic
2019	A Framework for Improving the Sharing of Teaching Practices Through Web 2.0 Technology for Academic Instructors	N. Almujally; M. Joy	0	Conference	Solution proposal	Prescriptive framework	Framework	Academic
2019	Reducing the Costs of Engineering Design Changes Through Adoption of a Decision Support and Knowledge Management System Early in the Design	R. K. Jonkers; K. E. Shahroudi	0	Conference	Solution proposal	No Framework	Guidelines	Academic
2019	Self-Optimization of Wireless Systems With Knowledge Management: An Artificial Intelligence Approach	H. Gačanin; E. Perenda; S. Karunaratne; R. Atawia	0	Journal/Magazine	Validation research	No Framework	Tool	Academic

Appendix B: Full keyword list

Keyword usage in the papers found in the IEEE Xplore database with the search term "Knowledge management framework"

Count	Keyword		
67	• Knowledge management		
17	• Knowledge engineering		
14	• Ontologies		
11	• Technology management		
9	• Companies • Technological innovation		
8	• Organizations		
7	• Decision making • Educational institutions	• Medical services	• Resource management
6	• Databases • Information technology	• Knowledge based systems	• Software
5	• Computer science • Data mining • Decision support systems	• Engineering management • Information management • Monitoring	• Project management
4	• Context modeling • Design engineering • Government	• Innovation management • Internet • Manufacturing	• Product design
3	• Business • Collaborative work • Computer architecture • Costs • Current measurement • Environmental management	• Humans • Information systems • Interference • Organizing • Process design • Prototypes	• Research and development • Systems engineering and theory • Testing • Water resources
2	• Application software • Asset management • Bit rate • Buildings • Communications technology • Computational modeling • Conference management • Context • Context awareness • Context-aware services • Data models • Design methodology • Diseases • Displays • Ecosystems • Educational technology • Electronic mail	• Engines • Fuzzy systems • Global Positioning System • Guidelines • Hardware • History • Information processing • Information retrieval • Interviews • Investments • Knowledge acquisition • Knowledge discovery • Knowledge representation • Libraries • Logic • Media • Medical diagnostic imaging	• Pediatrics • Pervasive computing • Production systems • Pulp manufacturing • Real-time systems • Reliability • Semantic Web • Social network services • Software engineering • Space technology • Statistical analysis • System testing • US Government • Virtual manufacturing • XML
1	• Access control • Acquired immune deficiency syndrome • Africa • Algorithm design and analysis • Ambient intelligence • Artificial intelligence • Asia • Assembly systems • Australia • Authentication	• Human immunodeficiency virus • Human resource management • Industrial engineering • Industries • Informatics • Information science • Information services • Intelligent agent • Intelligent networks • Intelligent sensors • Intelligent systems	• Protection • Publishing • Quality management • Radio link • Radio spectrum management • Radiofrequency identification • Refining • Relational databases • Remote sensing

- Authorization
- Bioinformatics
- Biomedical computing
- Biomedical measurements
- Books
- Business communication
- Channel allocation
- Circuit testing
- Civil engineering
- Code standards
- Command and control systems
- Communication standards
- Communication system control
- Communities
- Computer aided software engineering
- Computer applications
- Computer networks
- Computer science education
- Computers
- Concurrent engineering
- Conferences
- Contracts
- Costing
- Couplings
- Courseware
- Crisis management
- Crystallization
- Curriculum development
- Customer service
- Dairy products
- Data engineering
- Data security
- Discrete event simulation
- Dispatching
- Distributed computing
- Documentation
- Drugs
- Education
- Educational products
- Electronic commerce
- Electronic government
- Electronic learning
- Electronic publishing
- Embedded computing
- Environmental economics
- Europe
- Europe
- Extraterrestrial measurements
- Face
- Filtering
- Filtering algorithms
- Focusing
- Force
- Fuzzy logic
- Fuzzy reasoning
- Fuzzy sets
- Game theory
- Geometry
- Helium
- Hospitals
- International collaboration
- ISO
- Knowledge transfer
- Knowledge transfer
- Laboratories
- Laboratories
- Learning systems
- Lenses
- Life estimation
- Life testing
- Load management
- Loading
- Logic gates
- Machine tools
- Management information systems
- Management training
- Manufacturing industries
- Manufacturing processes
- Mass customization
- Mass production
- Materials
- Mathematical model
- Mathematics
- Mechanical engineering
- Memory management
- Merging
- Middleware
- Mobile communication
- Mobile handsets
- Modeling
- Moon
- Multi-agent systems
- Multimedia communication
- Multimedia computing
- Multimedia systems
- Natural languages
- Navigation
- Noise measurement
- Obesity
- Optimization
- Orbital robotics
- Outsourcing
- Peer to peer computing
- Personal digital assistants
- Personnel
- Planning
- Power engineering and energy
- Power system modeling
- Precision engineering
- Privatization
- Problem-solving
- Process control
- Processor scheduling
- Production facilities
- Productivity
- Profitability
- Programming
- Programming profession
- Prosthetics
- Requirements engineering
- Research and development management
- Risk management
- Rivers
- Robot motion
- Robot programming
- Robots
- Robustness
- Safety
- Scalability
- Scheduling
- Search methods
- Security
- Semantics
- Sensor phenomena and characterization
- Sensors
- Servers
- Service oriented architecture
- Sociology
- Software agents
- Software architecture
- Software measurement
- Software prototyping
- Software reusability
- Software systems
- Software testing
- Software tools
- Solid modeling
- Spirals
- Standards development
- Streaming media
- Stress
- Supply chain management
- Supply chains
- System dynamics
- Systematics
- Task analysis
- Telemedicine
- Terminology
- Throughput
- Tools
- Training
- Ubiquitous computing
- Uncertainty
- Unified modeling language
- Unmanned aerial vehicles
- US Department of Defense
- Water storage
- Web 2.0
- Web services
- Vehicles
- Wheels
- Video recording
- Videos
- Wireless communication
- Vocabulary
- Writing