Literature Review – Ontology Frameworks for Knowledge Management in Software Engineering

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Abstract

This literature review delves into the domain of Ontology frameworks for Knowledge Management in Software Engineering. Through a systematic analysis of selected primary studies, it becomes evident that ontologies play a crucial role in enhancing knowledge-sharing, collaboration, and decision-making processes within the SE domain. The review highlights the significance of precise domain definition and involvement in the development and utilization of ontologies. A total of 108 papers related to ontologies in KM or SE were identified, with 19 specifically focusing on frameworks, underscoring the importance of frameworks. The review process, guided by established methodologies, ensures the relevance and quality of the selected papers for analysis. This study contributes to a deeper understanding of the utilization of Ontology frameworks in KM in SE, emphasizing the diverse approaches and applications of ontologies in the Software Engineering domain.

Keywords

Knowledge Management, Software Engineering, Ontology, Framework

1. Introduction

Knowledge Management (KM) encompasses both practical business applications and academic exploration. It involves the systematic process of creating, sharing, using, and managing knowledge and information within an organization to improve efficiency and achieve strategic objectives. While the instinct to share knowledge is inherent, the formalization of KM within corporations is relatively recent. Initially rooted in commerce and industry, KM discourse has expanded into interdisciplinary realms, attracting scholars from various fields interested in the creating, sharing, and value of knowledge [1].

In the context of Software Engineering (SE), KM plays a crucial role in capturing, organizing, and leveraging the vast amount of knowledge generated during the software life cycle to enhance productivity and foster innovation [2]. The systematization, reuse, and sharing knowledge becomes even more important in software companies that have multiple teams, departments, or divisions that use different approaches, but at some point should cooperate [3]. Great fluctuation in the workforce in software companies may lead to the loss of knowledge (e.g. when experienced engineers leave the company), which strongly points out the importance of KM in the software industry.

Ontologies, on the other hand, provide a structured way to represent knowledge by defining concepts, relationships, and properties within a specific domain. They help identify inconsistencies and gaps and establish a shared vocabulary within a specific domain. This enables effective information sharing by defining fundamental domain concepts and their interrelationships[4]. Gruber[5] defines an ontology as "explicit formal specifications of the terms in the domain and relations among them."

By utilizing ontologies in Software Engineering, organizations can facilitate better knowledge-sharing, retrieval, and decision-making processes. Frameworks in the domain of KM in SE offer structure approaches and guidelines for implementing effective KM practices within Software

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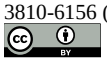

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Development processes. These frameworks help organizations streamline knowledge processes, enhance collaboration, and improve project outcomes.

This preliminary literature review on Ontology Frameworks for KM in SE contributes to the initial exploration of existing research in the field. By identifying and analyzing a selection of working papers that focus on Ontologies and KM within SE, this study initiates a systematic understanding of the current landscape.

In the Related Work section, a comprehensive review of some literature reviews on the application of Ontologies for KM in SE will be presented. The Methods Section provides details on the literature review process, including the search strategies employed and the inclusion/exclusion criteria used to select relevant studies. The Results and Discussion section presents the findings from the selected primary studies. Finally, the Conclusion provides a summary of the key insights gained and suggests future research directions in Ontology frameworks for KM in SE.

2. Related Works

This section outlines some recent studies that present literature reviews on using ontologies for knowledge management issues in the software engineering domain. Reviewing scientific papers (not necessarily case studies) that deal with ontologies may significantly contribute to developing the research field and indicate challenges for further research.

Junior et al. [6] presented a systematic literature review (SLR) on tools, models, techniques, and practices utilizing ontology as an aid to Distributed Software Development (DSD). The authors proposed the following research questions that guided their review: (1) Which tools, techniques, models, and practices based on ontologies are used in DSD, and (2) which ontologies were proposed in the field of DSD? Totally 37 primary studies were identified and used for constructing the findings. Identified tools, models, and ontologies were classified based on the phase in the software life cycle proposed in SWEBOK [7]. The following ontologies were identified: Software components, OFFLOSC – Ontology for supporting open source development communities, Open source communities, and ONTODISEN – Ontology to support global software development. Based on the literature review 10 models, 22 tools, 11 practices, and 3 techniques that use ontologies were identified. Regarding the classification of ontologies according to software life cycle phases proposed in SWEBOK, most ontologies relate to software processes in general.

Triandini et al. [8] presented a systematic literature review of the role of ontology in modeling knowledge in software development. The findings provide answers to research questions related to the role of ontology in modeling and the challenges of using ontologies in software engineering. Use of ontologies in software modeling includes modeling data in software development, database, and application integration, using vocabulary for describing knowledge, assistance in software testing, resolving problems with change of software requirements, use in Internet of Things (IoT) systems, quality assessment and improvement of software development, detecting change in software systems, and use of patterns in development. The main identified challenges for using ontologies in software engineering are software development improvement, knowledge abstraction, limited knowledge in malware detection, evaluation of used ontologies, management in software development, ontology in the context of software security, and problems in adjusting to project plans in software development.

Osman et al. [9] present a review of ontology-based knowledge management tools for knowledge sharing in organizations, based on the following comparison criteria: motivation, domain knowledge, source of knowledge, types of knowledge, knowledge extraction, knowledge input process, knowledge retrieval process, knowledge sharing technology, source of ontology component, and ontology methodology. A total of 13 primary studies were identified through filtering studies. Identified tools were used in a variety of domains such as software engineering, education, healthcare, building and construction, decision support systems, economics, etc. The main conclusion of the authors is that tools are specific for narrow domains and that humans are the main source of knowledge. The development and use of ontologies are tightly connected to a precise definition of a domain and scope of knowledge. In contrast, the development process might be manual (from scratch), or by using some tools for automating steps in the development process.

Agbaegbu et al. [10] presented a comprehensive review of existing literature on the application of ontologies in cloud computing. The study aims to identify the evolution of ontology in cloud computing dominant areas of ontology application, less explored areas, challenges faced, and future research directions. The methodology includes the SLR approach, where 400 articles were identified, and 35 relevant articles were selected based on set criteria. The study highlights the impact of cloud ontologies in areas such as cloud security, interoperability, resource description, and service discovery. It also discusses the challenges in applying ontologies to enhance business operations in the cloud and multi-cloud environments. The authors' research aims to provide insights into unresolved challenges and suggest potential future directions for researchers in cloud ontology.

In addition, recent research trends suggest the use of ontologies in domains such as systems engineering [11] and systems of systems [12], which are complex systems that commonly include software systems. Further, Kotis and Vouros [13] suggested that continuously exploring and evaluating ontologies is necessary since ontologies may change in the evolving context, which indicates the need for active involvement of all relevant stakeholders during the ontology life cycle.

3. Methods

A more comprehensive literature review related to frameworks, methods, and models in Knowledge Management within Software Engineering has been performed. The initial objective was to investigate the activities and focus areas of individuals in the field. Our research concluded that frameworks, models, and methods are commonly employed to address specific problems. The objective of this paper is to focus solely on the review of frameworks in Knowledge Management in Software Engineering based on Ontologies.

Certain procedures for the literature review used in this study are adapted from [14]. While our study is not a comprehensive Systematic Literature Review, specific methodologies presented in Chapter 22 of the book [14] were employed to guide our Literature Review process, which is shown in Figure 1.

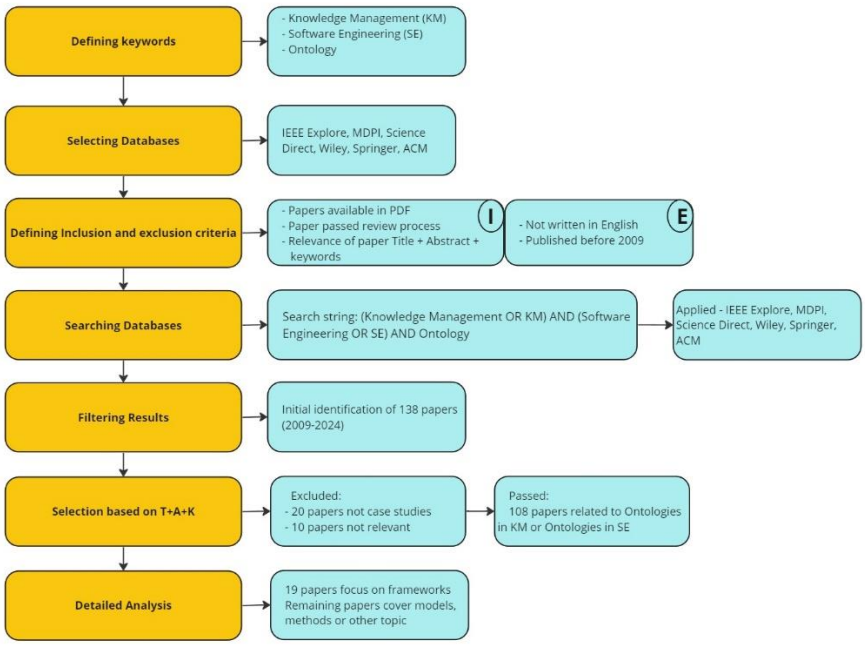

Figure 1: Literature Review process

As seen in Figure 1. yellow blocks show Phases of the literature review, while cyan blocks show the outputs of each phase.

For this preliminary Literature Review, three primary keywords were proposed:

- Keyword 1 (KW1) – "Knowledge Management" OR "KM"
- Keyword 2 (KW2) – "Software Engineering" OR "SE"
- Keyword 3 (KW3) – "Ontology"

These three primary keywords represent essential concepts guiding the search for relevant literature. To enhance the precision of the literature search, logical operators were employed to combine search terms. The Boolean operators AND and OR were utilized to connect key concepts within the search of a string. Combining these three keywords, the following search string was formed:

KW1 AND KW2 AND KW3

This literature search string was applied across databases such as IEEE Explore, MDPI, ScienceDirect, and Wiley. An additional search to find out some papers not published in the stated databases was performed by using the Google Scholar Web Search Engine.
The selection of papers for this preliminary Literature Review adhered to specific inclusion criteria.
Proposed inclusion criteria are: (I1) Only papers that are available in PDF format were considered to ensure accessibility; (I2) Papers that passed the review process (peer-reviewed journals and conference proceedings); (I3) The relevance of the paper's title, abstract, and keywords (T+A+KW) ensuring alignment with the research focus.
To ensure the relevance and quality of the literature selected for this preliminary review certain exclusion criteria were applied. Used exclusion criteria are: (E1) Papers that are not written in English; (E2) Papers that were published before 2009.
Based on the specified search string and the inclusion and exclusion criteria, the search was conducted across selected databases. A total of 138 papers published between 2009 and 2024 were identified. Upon briefly reading the text of the collected research papers, it was concluded that 20 papers were not case studies, and 10 did not correspond to the topic. The remaining 108 papers, which are related to the thematic fields of Ontologies in Knowledge Management or Ontologies in Software Engineering were included for more detailed analysis.
A detailed analysis of these 108 papers revealed that 19 specifically focus on frameworks, while the remaining papers address models, methods, or various other topics. These 19 research papers were selected as primary studies (PS) and are presented in Table 1.

Table 1
Selected primary studies

Primary Studies	Reference	Year
PS1	Ribino, P., Oliveri, A., Re, G. L., & Gaglio, S. (2009, June). A knowledge management system based on ontologies. In 2009 International Conference on New Trends in Information and Service Science (pp. 1025-1033). IEEE.	2009
PS2	Tuan, D. T., & Tuan, D. C. (2011, October). Enhance Java Software Development with Knowledge Acquisition and Management Tools. In *2011 Third International Conference on Knowledge and Systems Engineering* (pp. 70-77). IEEE.	2011
PS3	Zheng, Y. L., He, Q. Y., Ping, Q. I. A. N., & Ze, L. I. (2012). Construction of the ontology-based agricultural knowledge management system. *Journal of Integrative Agriculture*, *11*(5), 700-709.	2012
PS4	Moser, T., & Biffl, S. (2011). Semantic integration of software and systems engineering environments. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, *42*(1), 38-50.	2011
PS5	Gobin, B. A. (2012, November). A domain ontology for capturing knowledge for social integration. In *2012 Tenth International Conference on ICT and Knowledge Engineering* (pp. 194-200). IEEE.	2012
PS6	Jin, F., Zhang, X., & Liu, W. (2014, October). Enterprise Knowledge Management Platform Based on Fuzzy Ontology. In *2014 International Conference on Management of e-Commerce and e-Government* (pp. 246-251). IEEE.	2014

PS7	Ramona-Cristina, P., Vasilateanu, A., & Goga, N. (2016, October). Ontology-based multi-system for SME knowledge workers. In *2016 IEEE International Symposium on Systems Engineering (ISSE)* (pp. 1-5). IEEE.	2016
PS8	Knauss, E., Liebel, G., Schneider, K., Horkoff, J., & Kasauli, R. (2017, September). Quality requirements in agile as a knowledge management problem: More than just-in-time. In *2017 IEEE 25th International Requirements Engineering Conference Workshops (REW)* (pp. 427-430). IEEE.	2017
PS9	Yuan, E. (2017, May). Towards ontology-based software architecture representations. In *2017 IEEE/ACM 1st International Workshop on Establishing the Community-Wide Infrastructure for Architecture-Based Software Engineering (ECASE)* (pp. 21-27). IEEE.	2017
PS10	Alsanad, A. A., Chikh, A., & Mirza, A. (2019). Multilevel ontology framework for improving requirements change management in global software development. *IEEE Access*, *7*, 71804-71812.	2019
PS11	Abioye, T. E., Arogundade, O. T., Misra, S., Akinwale, A. T., & Adeniran, O. J. (2020). Toward ontology-based risk management framework for software projects: an empirical study. *Journal of Software: Evolution and Process*, *32*(12), e2269.	2020
PS12	Von Rueden, L., Mayer, S., Beckh, K., Georgiev, B., Giesselbach, S., Heese, R., ... & Schuecker, J. (2021). Informed machine learning–a taxonomy and survey of integrating prior knowledge into learning systems. *IEEE Transactions on Knowledge and Data Engineering*, *35*(1), 614-633.	2021
PS13	Bernasconi, E., Di Pierro, D., Redavid, D., & Ferilli, S. (2023). SKATEBOARD: Semantic Knowledge Advanced Tool for Extraction, Browsing, Organisation, Annotation, Retrieval, and Discovery. *Applied Sciences*, *13*(21), 11782.	2023
PS14	Uwasomba, C. F., Lee, Y., Yusoff, Z., & Chin, T. M. (2022). Ontology-Based Methodology for Knowledge Acquisition from Groupware. *Applied Sciences*, *12*(3), 1448.	2022
PS15	Elhabbash, A., Elkhatib, Y., Nundloll, V., Marco, V. S., & Blair, G. S. (2024). Principled and automated system of systems composition using an ontological architecture. *Future Generation Computer Systems*.	2024
PS16	Hasan, N., Rahman, M. H., Wessman, A., Smith, T., & Shafae, M. (2023). Process Defects Knowledge Modeling in Laser Powder Bed Fusion Additive Manufacturing: An Ontological Framework. *Manufacturing Letters*, *35*, 822-833.	2023
PS17	Zhang, L., Olsen, A., & Lobov, A. (2022). An ontology-based KBE application for supply chain sustainability assessment. *Resources, Environment and Sustainability*, *10*, 100086.	2022
PS18	Nazir, S., Motla, Y. H., Abbas, T., Khatoon, A., Jabeen, J., Iqra, M., & Bakhat, K. (2014, November). A process improvement in requirement verification and validation using ontology. In *Asia-Pacific World Congress on Computer Science and Engineering* (pp. 1-8). IEEE.	2014
PS19	Ghaisas, S., & Ajmeri, N. (2013). Knowledge-assisted ontology-based requirements evolution. In *Managing requirements knowledge* (pp. 143-167). Berlin, Heidelberg: Springer Berlin Heidelberg.	2013

4. Results and Discussions

From the primary studies, through detailed reading and analysis of research papers, 11 types of frameworks were identified and presented in Table 2.

Table 2
Types of frameworks

Types of Frameworks	Primary Studies
Knowledge Management FW	PS1, PS3, PS4, PS6, PS8, PS10, PS13, PS16
Software Development FW	PS2
Ontology Development FW	PS5
Information Utilization FW	PS7
Software Architecture Modeling FW	PS9
Risk Management FW	PS11
Machine Learning Taxonomy FW	PS12
Knowledge Harvesting FW	PS14
System of Systems FW	PS15

Knowledge Representation FW	PS17
Ontology-based Requirements Engineering FW	PS18, PS19

In the realm of KM, various frameworks have been developed and utilized to enhance the organization and utilization of knowledge. The primary studies that discuss or utilize knowledge management framework include [PS1][PS3][PS4][PS6][PS8][PS10][PS13][PS16]. Studies [PS18] [PS19] explore ontology-based requirements engineering frameworks, which utilize ontological approaches to enhance the requirement engineering process. In addition to these, there are frameworks specifically focused on Software Development, Ontology development, Information Utilization, Software Architecture Modeling, Risk Management, Machine Learning Taxonomy, Knowledge Harvesting, System of Systems, and Knowledge Representation.

From primary studies, various domains that focus on the development or utilization of frameworks were identified. These domains, along with their corresponding primary studies are presented in Table 3.

Table 3
Categorized domains based on primary studies

Domains	Primary Studies
Additive Manufacturing	PS16
Knowledge Management	PS1, PS3, PS6, PS8
Distributed Systems	PS15
Engineering	PS4
Knowledge Acquisition	PS14
Semantic Technologies	PS13
Knowledge	PS5
Machine Learning	PS12
Product Lifecycle Management	PS17
Requirements Engineering	PS18, PS19
Software Engineering	PS2, PS9, PS10, PS11
Software Implementation for SMEs	PS7

Knowledge Management frameworks are a significant area of focus, with primary studies [PS1][PS3][PS6][PS8]. Software Engineering is another major domain with [PS2][PS9][PS10][PS11]. In the field of Requirements Engineering, there are studies [PS18] and [PS19]. There are also other domains such as Additive Manufacturing, Distributed Systems, Engineering in general, Knowledge Acquisition, Semantic Technologies, Knowledge, Machine Learning, Product Lifecycle Management, and Software Implementation for SMEs.

4.1. Constraints and validity

Literature reviews in software engineering need to adjust to validity criteria to properly address identified threats and increase the reliability and usability of reported findings [15]. The authors are aware of potential threats to validity, such as the construction of a search string, selection of databases to search, assessment of the quality of selected papers, and construction of the findings. Discussion of two important aspects of validity, named internal and external validity contributes to the soundness of the research process and reliability of the findings.

Presented details on planning and conducting a literature review are essential for addressing internal validity, which is done in the third section of the paper. Based on the description of the review process,

including the search for papers and their analysis, enables traceability from findings to the selected primary studies. This increases the reliability of the presented findings. External validity relates to the generalizability of the findings. Since the findings are specific to the stated field, there is no intention to generalize findings to other fields in software engineering. However, the authors suggest that the presented literature review process can be generalized and applied in other fields.

5. Conclusion

This preliminary Literature Review has provided valuable insights into the utilization of Ontology frameworks for KM in SE. Through the analysis of selected primary studies, it is evident that ontologies play a crucial role in structuring and organizing information in various domains, including Software Engineering, Education, Healthcare, and Decision Support Systems. The review highlighted the importance of precise domain definition and human involvement in the development and use of Ontologies.

Furthermore, the study identified a total of 108 papers related to ontologies in KM or SE, with 19 specifically focusing on frameworks. This underscores the significance of frameworks in addressing specific problems within the field. The review process, guided by methodologies adapted from existing literature, ensured the relevance and quality of the selected papers for analysis.

This paper contributes to the understanding of the role of Ontological frameworks in KM in SE through the analysis of relevant literature. The identification of key words and the classification of framework types provide insight into the diversity of approaches and applications of Ontologies in the domain of SE. Through the analysis of selected studies, the paper emphasized the importance of ontological frameworks in organizing information, facilitating collaboration, and improving the decision-making process in SE.

Looking ahead, the insights and findings from this review lay the groundwork for future investigations into Ontology frameworks for KM in SE. By addressing existing research gaps and exploring emerging trends, researchers can further enhance the effectiveness of Ontologies in facilitating KM processes within the SE domain. Future research could focus on the development, implementation, and evaluation of Ontology frameworks tailored to specific domains within SE, or other fields of human work and life. These frameworks could address evolving challenges in KM and offer innovative solutions for information organization.

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