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Ontology-Based Knowledge Management Tools for Knowledge Sharing in Organization—A Review

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ABSTRACT Knowledge management (KM) comprises several processes, and one of the most important is the knowledge sharing activities. The ability of an organization to manage its organizational knowledge, specifically in the context of knowledge sharing, may enhance the organization's overall performance. Various approaches and technologies have been introduced to assist the process in achieving that target. Ontology as one of the knowledge representation methods has been becoming popular to assist knowledge sharing in the organization. Previous reviews have mainly focused on general KM issues, with little emphasis on the use of ontology in knowledge sharing. Thus, this article reviews several ontology-based KM tools that can support knowledge-sharing activities to provide some insight into future research in this area. Thirteen ontology-based KM tools were reviewed using ten elements' comparison criteria: the motivation, domain, source of knowledge, type of knowledge, knowledge extraction, knowledge input process, knowledge retrieval process, knowledge sharing technology, source of ontology component, and ontology methodology. The review found that several elements can be further studied to improve KM implementation in the organization, especially on the knowledge sharing dimension. This includes simplifying the knowledge extraction and retrieval process to explore various knowledge domains from implicit knowledge sources. The review's outcome also includes proposed components and functions of an ideal ontology-based KM tool.

INDEX TERMS Knowledge, knowledge management, knowledge sharing, ontology, organization.

I. INTRODUCTION

Effective knowledge management is a critical point in every organization to drive organizational excellence to the highest level. All organization members should be able to adapt and implement knowledge management practices, among others, through the implementation of knowledge sharing activities. Knowledge sharing activities in an organization can be defined as transmitting the organizational knowledge among the organization's members to conduct planned activities [1]. Knowledge sharing is a two-way activity between and among employees in the organization's environment. It is a mutual learning process since one side benefits from the expertise and learning of the other, resulting in a competitive advantage for the company [2]. To ensure that knowledge sharing can be successfully adopted, the organization must focus on individual factors [3], [4]. On the other hand, the organization's management should provide suitable medium

and equipment to ensure the implementation of knowledge sharing is successful and subsequently achieve the targeted goals.

There has been no consensus among researchers regarding the definition of knowledge management. Based on our literature review, various researchers define knowledge management based on context, domain, and application [5]–[12]. However, one of the relatively comprehensive definitions defines knowledge management as a systematic process of acquiring, organizing, sustaining, applying, sharing, and renewing all forms of knowledge [13]. The definition shows that several processes were involved in the implementation of knowledge management, starting from the process of acquiring to the process of sharing and renewing the knowledge. On top of that, another critical aspect observed is the compulsory existence of the knowledge-sharing process in the implementation stages of knowledge management [5]–[12].

Various synergies can be generated by the organizations which implement knowledge management in their daily operations. Some advantages of knowledge management include

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increasing human resources productivity, services, and customer satisfaction while saving time and reducing repetitive work [11]. In addition, the availability of efficient and effective knowledge management tools will assist in implementing knowledge-sharing activities in the organization. For that purpose, information technology tools can perform actions and tasks more quickly and support the knowledge-sharing process [14].

Various technologies and tools have been introduced to assist in implementing knowledge management in organizations. Knowledge management-related technologies can be categorized according to their strategy, process, and level of technology [15]. The tools capable of carrying out the task include computer systems, the internet, artificial intelligence, data mining, the internet of things, cloud computing, and machine learning [16]. With the advancement of technology, these tools have evolved with more advanced features and capabilities.

Knowledge representation is one of the technologies closely related to knowledge management. Knowledge representation is responsible for managing the exchange of knowledge sources into a form that the computer can understand. One of the knowledge representation techniques, ontology, is used in various application domains by facilitating a common understanding of the information structures [17]. Apart from that, ontologies should play a direct role in knowledge sharing activities and represent the knowledge in a specific domain [18], [19], as study shows that ontology can support all knowledge management processes [20], [21].

Ontologies can play a role in facilitating the implementation of knowledge sharing in organizations because they can establish a common conceptualization [22] while also facilitating communication between people or software agents by providing a shared understanding of the knowledge terms exchanged [23]. Aside from that, an ontology may define a term's meaning, allowing for interoperability, information reuse, and knowledge sharing [19]. Overall, the role of ontology in knowledge sharing is primarily related to their ability to support all knowledge management processes, their ability to exchange knowledge in a form that a computer can understand, and their ability to facilitate communication through shared understanding of knowledge terms and the ability to provide descriptions on terms.

Knowledge management tools refer to repositories, knowledge management systems, or information retrieval systems [24]. These traditional knowledge management technologies, on the other hand, were created using non-intelligent technology and hence are unable to give sophisticated capabilities. As a result, enhanced knowledge management technologies with ontology and inference engines have been proposed [25]. Incorporating an ontology in a knowledge management tool will help with the knowledge management process [19], allowing for searches that go beyond traditional keyword searches and making knowledge more shared and extendable. As a result, ontology-based knowledge management solutions are best described

as integrating an ontology with knowledge management systems to enhance the tools' intelligence.

Gruber's definition [26] of an ontology as "a specification of a conceptualization" fits well for knowledge sharing activities because an ontology is viewed as a description (like a formal specification of a programme) of the concepts and relationships that can exist for a community of users or even among integrated systems. This definition is consistent with ontology usage as a set of concept definitions but more general. In other words, an ontology is a specification used for making ontological commitments.

The current situation indicates an increasing interest among researchers to study the relations of knowledge representation in the implementation of knowledge management. Thus, this paper aims to review ontology-based KM tools that can support knowledge sharing activity to provide future research direction in this area. The review was conducted by comparing and contrasting selected tools using comparison criteria that identified essential information and attributes in the related literature.

II. RELATED WORKS

Researchers carried out a variety of literature reviews related to knowledge management, encompassing numerous topics. Sohrabi *et al.* [27] analysed knowledge management-related papers and discovered that the technology and KM processes perspectives had gained increasing attention in recent years. Rokhman *et al.* [28] reviewed the use of ontology in knowledge management, specifically in the academic domain, by looking into the type of ontology that has been made to support knowledge management in academic organizations and the knowledge management process that uses the ontology. Another study by Wang *et al.* [29] discovered ontology as an important topic in knowledge management research after doing a keyword analysis on the articles. Centobelli, Cerchione & Esposito [30] looked into articles on the subject of KM and discovered some concerns, including the factors that drive KM adoption, the absence of a KM system taxonomy to assist the KM process, the alignment of strategies and technologies used, and the effect of KM. Another research by Gao, Chai and Liu [31] reviewed the theoretical conception of KM and the approaches of designing KM from several aspects comprehensively.

Although several review articles on KM implementation in organizations were published previously, we observed that reviews on ontology-based KM tools are still lacking. We will concentrate on different perspectives in this article by reviewing papers that focus on using ontology for knowledge management solutions in their implementations.

III. ARTICLES SELECTION

Bibliometric analysis, systematic literature review, narrative reviews, and tertiary reviews are some of the methods and approaches used for reviewing articles. Hannah Snyder [32] mentioned that the review's objective determines the selection of methods. All of them can be useful in achieving a

specific goal, given that the method may require additional refinement.

Bibliometric analysis is a tool for quantitatively assessing academic papers using statistical techniques [33]. This technique allows the articles to be classified and offers overviews of the influence and trends on the studied topic [34]. Systematic literature review instead is described as a review of a clearly specified issue that attempts to reduce bias by selecting, evaluating, and summarizing relevant research using a systematic and explicit approach [35]. Usually, the review that applies this method was conducted using databases searches to retrieve the result of the research [36]. Another method is the narrative reviews, which aim to describe and evaluate published articles but do not specify how the articles were chosen [37]. Narrative reviews may be used to investigate the research that looks into the impact, variables, needs, and causes of a particular scenario or problem [38]. Tertiary reviews, on the other hand, are systematic reviews in which the studies included are also systematic reviews, with the purpose of presenting the systematic reviews' findings while simultaneously analysing the methodological quality of the systematic reviews [39]. This approach will address broader research issues [40].

This research applies the systematic literature review by combining and refining a method proposed by Charband & Jafari Navimipour [41] and Iskandar *et al.* [42]. The authors divided the procedure into three phases. This approach is the most suitable method to use, considering that most of our targeted articles are available in online academic databases, and the implementation suits our review objectives. The first stage involved finding online articles through the use of online resources. Searching was conducted on online academic databases, including but not limited to IEEE Xplore Digital Library, ScienceDirect, ACM Digital Library, Springer Link, Sage Journals Online, and Google Scholar links. The search is limited to materials published after 2010 to ensure that the search results return recent publications. According to another criterion, only journal articles and conference proceedings will be included. At this point, a selection and a combination of several keywords were applied. The keywords include “knowledge management,” “tool,” “knowledge base”, “knowledge sharing” and “ontology”.

In the second stage, all of the gathered articles were filtered based on their titles and abstract contents, ensuring that only relevant articles were chosen. The availability of knowledge management tools and ontology components were the determining factors. At this point, any articles not relevant to the review objective were deleted. Finally, the entire text was read, the substance was assessed, and the comparison criteria were identified. All important information was recorded for further analysis. At the end of the selection process, 13 articles fulfilled the predetermined criteria and satisfied the filtration settings. Table 1, Figure 1 and Figure 2 show the analysis and statistics of the selected papers, organized by the year of publication and publisher.

TABLE 1. Articles summary by publishers and years.

Publishers	2010	2013	2014	2015	2016	2017	2018	2019
IEEE	1			1		2	1	
Springer Link		1						
Science Direct			1		1	1	1	1
ACM						1		
Sage Journal								1

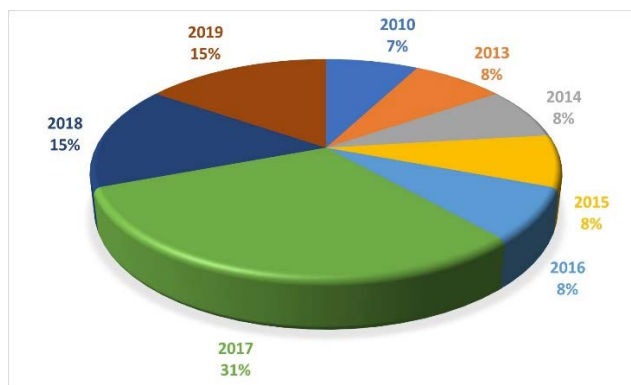


FIGURE 1. Articles percentage by years.

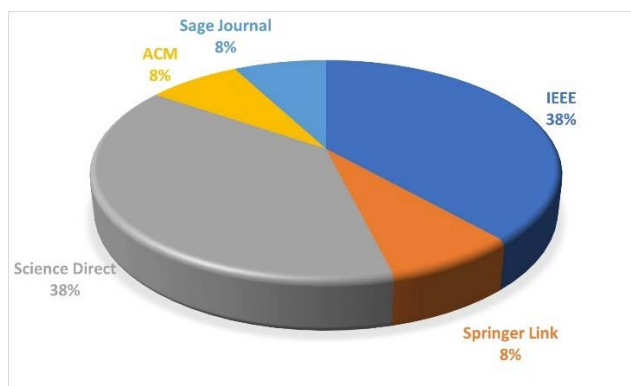


FIGURE 2. Articles percentage by publishers.

IV. TYPES OF KNOWLEDGE

Scholars typically distinguish knowledge into two different categories: explicit and tacit knowledge. Explicit knowledge is commonly recognized as the knowledge that can be represented by a system of symbols that can be articulated, codified, transferred, and expressed in multiple mediums such as writing, drawings, or computer programs [13], [43], [44]. This knowledge has become the center of attention in KM based on the fact that this knowledge can be codified. The codification of the knowledge is the most crucial part of KM, as codified knowledge will allow better dissemination of the knowledge in the organization.

TABLE 2. Knowledge management issues.

Authors	Year	Issues
Shaw & Liu [51]	2016	Difficulties in collecting the tacit knowledge
Sukumaran et al. [52]	2018	<ul style="list-style-type: none"> • Adoption of Communities of Practice in the Workplace • Reward and Recognition for Knowledge Workers • Special Attention to the Design of KM Technology • Develop Knowledge-Sharing Habits • Managerial Context of Knowledge-Sharing Behaviour • Social Context of Knowledge Sharing Behaviour
Theocharis et al. [53]	2016	The use of appropriate technology to assist the implementation of KM
Iskandar et al. [42]	2017	<ul style="list-style-type: none"> • Need to Explore the Features Related to The Ability of Knowledge Management • Big Data Research Trends • The Use of Technology That Supports Knowledge Management Process

The second type of knowledge is tacit knowledge, defined as uncodified and undocumented knowledge [45], [46]. Tacit knowledge is personal and action-oriented, which is accumulated in the minds of an individual (where it resides) in the form of thoughts, cognitive, and intuitive perceptions [47], [48] and can be transformed into explicit knowledge with the aid of tools [49]. Tacit knowledge is the most valuable knowledge in the organization as this knowledge can foster innovation and encourage learning in the organization. However, the transference of this knowledge is said to be slow and expensive [50].

V. KNOWLEDGE MANAGEMENT ISSUES

Implementing KM in organizations will take a lot of effort and determination. Several factors need to be considered before an organization can fully adapt KM in its daily operation. The most common issue highlighted in the implementation of KM is the difficulties in collecting tacit knowledge [51].

Apart from that, an organization might need to put some attention on several factors such as the adoption of Communities of Practice in the workplace, reward, and recognition for knowledge workers, put attention on the KM technology design, develop knowledge sharing habits, and organizational and social context of knowledge sharing behavior, as these elements can influence the implementation of KM in organizations [52]. The use of appropriate technology to assist in implementing KM is another critical issue that needs to be addressed [53]. Another issue that most scholars might be interested in exploring is the need to identify the features related to the ability of knowledge management, significant data research trends, and the use of technology that supports the KM process [42]. The summary of the issues is presented in Table 2.

Referring to Table 2, the hovering issues, among others, focus on the topic of knowledge management tools that can

support knowledge sharing implementation in organizations. In this regard, ontology-based knowledge management tools appear to address several related issues, as the ontology can deal with information organization, information retrieval, and system interoperability issues [54].

VI. OBJECTIVE OF THE PAPER

The primary goal of this paper is to review existing ontology-based KM tools that can support knowledge-sharing activities to provide helpful information for future research directions. The reviews were conducted by assessing selected tools using comparison criteria developed by identifying important information and characteristics in the related literature. Also provided is a diagram describing the concept of an ideal ontology-based knowledge management tool's components and processes.

VII. CRITERIA OF COMPARISON

The criteria used in this review are based on a combination of criteria derived from the study of related works of literature [[16], [20], [55]–[57]]. Ten criteria are being proposed, including the motivation, the knowledge domain, the source of knowledge, and the type of knowledge. On top of that, knowledge extraction, knowledge input process, knowledge retrieval process, and type of KM technology also were studied. Lastly, this article also investigates the application of ontology by identifying the source of ontology and the methods of building ontology.

A. MOTIVATION

Researchers conducted a study based on the problem that has been identified through various methods. The situation in handling and managing knowledge in organizations has led to the research on KM tools which is crucial to ensure that the KM tools manage to perform a task that allows employees to connect and use it directly [12], [58]. The criterion motivation refers to why the tools were being introduced or what motivates the development of the tool.

B. DOMAIN KNOWLEDGE

There is a wide range of knowledge available in the organization, and this knowledge can be found in a variety of domains. Domain knowledge can be defined as the knowledge of a specific, specialized discipline, profession, or activity. The term is used to characterize the knowledge of specialists or experts in a particular topic [59]. Examples of domain knowledge in organizations include education, economy, health, engineering, and information technology. The development of KM tools usually focuses on a specific domain in organizations. The identification of this domain can aid in gaining a better understanding of how knowledge is managed and provide helpful insight into the KM area.

C. SOURCE OF KNOWLEDGE

The source of knowledge refers to the origin of the knowledge either from experts (human) or other physical sources such as

documents, web pages, and social media posts. Aside from that, Van Woudenberg [60] contends that reading should be regarded as a source of knowledge because it frequently interacts with other sources to produce cognitive consequences. This identification of knowledge source step is required to facilitate the identification of knowledge types later.

D. TYPES OF KNOWLEDGE

As stated in the preceding section, the two most commonly used types of knowledge are tacit and explicit knowledge. Tacit knowledge refers to knowledge embedded in the human mind. In contrast, explicit knowledge is codified and digitized in books, documents, web portals, etc. O. Serrat [44] mentioned that tacit and explicit knowledge are two types of knowledge that complement each other. Thus, this criterion examines the type of knowledge used.

E. KNOWLEDGE EXTRACTION

Before the knowledge can be further processed, the KM tools must extract it into a form that computers can understand. Knowledge extraction is one of the challenges in implementing knowledge management in organizations besides the enormous diversity and vast amount of data and information [61]. Furthermore, extracting knowledge from a document is challenging since most documents lack the structure of a database and lack semantics in their interpretation [62]. In this paper, we distinguish the extraction process into automatic and manual. Automatic refers to the system's ability to extract knowledge without human intervention, whereas manual refers to the manual input process.

F. KNOWLEDGE INPUT PROCESS

This criterion aims to identify methods and processes used to input the knowledge into the KM tool. The knowledge input process refers to the technique used by the KM tool to capture knowledge from knowledge sources such as annotation, tagging, and indexing.

G. KNOWLEDGE RETRIEVAL PROCESS

Knowledge retrieval is among the important indicators to ensure that knowledge sharing is being implemented. The knowledge retrieval method described how a user might access and obtain information from the KM tool. This is an essential step in the knowledge sharing process because the knowledge that has been input into the system must be made available for users to access and retrieve after it has been processed. This criterion heavily influences the goal of developing KM tools, and their success can be measured by the KM tool's ability to provide knowledge to the intended users. In some cases, using an ontology seems to improve retrieval effectiveness [63].

H. KNOWLEDGE MANAGEMENT TECHNOLOGY

Various technologies can be used to share knowledge, and these technologies have evolved from essential functions to the most sophisticated features. Most researchers also choose

to create a hybrid system by combining several technologies. Ontology, knowledge management systems, and social media applications are examples of technologies employed in KM tool development. This criterion identifies the KM technology in the individual reviewed pieces of literature.

I. SOURCE OF ONTOLOGY

The knowledge domain and scope need to be defined before the ontology can be developed. As a result, researchers must identify the ontology source to explicitly explain the domain and scope. The origin of the knowledge utilized to create the ontology is referred to as the source of ontology. Due to the variety of knowledge sources, ontology is ideal for semantically representing knowledge by integrating and organizing it into a conceptual hierarchy [64].

J. ONTOLOGY DEVELOPMENT METHODOLOGY

Various methods are currently in existence to build ontologies. A methodology for constructing ontologies describes the steps involved in creating the ontology. Ontologies may be created manually from scratch by combining existing ontologies or learned automatically or semi-automatically using an ontology learning process [65]. According to Espinoza-Arias *et al.* [66], methods for developing ontologies are intended to assist developers through the entire process, to transform the art of building ontologies into an engineering process. The technique employed by the researchers to build the ontology is identified and presented by this criterion.

VIII. REVIEW OF KNOWLEDGE MANAGEMENT TOOLS FOR KNOWLEDGE SHARING

A. ONTOLOGY-BASED KNOWLEDGE SHARING PORTAL FOR SOFTWARE TESTING

S. Vasanthapriyan *et al.* [22] utilize ontology as a knowledge representation technique in the software testing knowledge domain. The goal of the study was to develop a reliable method for software testers to exchange their knowledge on software testing. Software development is prone to errors, so software testing is needed to produce high-quality software. The study was based on the researcher's conclusions that current repositories are obsolete, documents exist in various formats and are unstructured, accessing capabilities were limited, and targeted distribution methods are lacking. As a result, software testers have difficulty performing software testing since they cannot obtain critical information from the repository.

The first step taken by the researcher is to build software testing domain ontology. The researcher chooses Gruninger and Fox's formal approach to creating ontology. This ontology offers software testers context-specific information and expertise. To understand the software testers' context, knowledge of software testing was extracted from existing literature and by interviewing the software testing experts. The ontology concepts, properties, and relationships were then

identified. Competency Questions (CQ) were then applied to ensure that the ontology was correctly created.

The knowledge-sharing portal architecture consists of five layers: experience sharing, ontology, storage, reasoning engine, and knowledge retrieval layer. The knowledge sharing procedure begins with software testers manually annotating their testing knowledge in the experience sharing layer's system interface. The software testing variable cloud, already specified in the ontology layer, aids the annotation process. The shared knowledge is then transformed into semantic data and expressed in triple structures based on the created ontology's concepts and relationships. The reasoning engine creates reasoning data based on ontology, domain rules, and semantic data stored in the storage layer. Finally, users can use the search and advanced search functions on the application interface to find relevant content.

For ontology quality evaluation, three main approaches were used: internal consistency checking using reasoners, OOPS! Web-based evaluation, ontology expert evaluation, and ontology non-expert evaluation. Based on the evaluation, the researchers conclude that incorporating the software testing ontology on the knowledge sharing portal can improve knowledge sharing in organizations and thus foster learning practices in software testing.

B. ONTOLOGY-BASED KNOWLEDGE REPOSITORY FOR BUILDING AND CONSTRUCTION

Costa *et al.* [67] proposed an approach to facilitate knowledge sharing in the building and construction (B&C) domain by using an ontology. Their goal is to codify and represent document content, as most current approaches focus solely on explicit and word-based data. Traditional knowledge representations were augmented in this study by combining implicit information from domain ontologies with information from the document. The study proposed a conceptual framework for representing knowledge sources, in which each source is represented semantically. The availability of project data in the historical project information repository can improve future project performance, such as on-site construction problem-solving.

The model of B&C knowledge consists of three categories: the classification system and thesauri, product and process models, and ontologies. Inspired by e-COGNOS ontology, the domain ontology includes seven major domains: project, actor, resource, product, process, technical topic, and related domains. All entities have three ontological dimensions: the state that captures entity development status whether dormant, executing, stopped, re-executing, or completed. The second dimension is the stage which defines the development stages such as conceptualization, planning, implementation, and utilization. The third and final dimension is the situation that refers to planned and unplanned entities.

The first step in enriching knowledge representation is finding appropriate knowledge sources in the ICONDA digital library, an online resource for planning and developing domain-related publications. The repository was used

to collect and store all essential knowledge sources. B&C knowledge expert will then inspect all knowledge sources and pre-label all the relevant knowledge. The K-Means clustering method was used to classify knowledge sources into multiple groups. Finally, an evaluation was conducted to measure performance for the overall approach using classical precision (relevant instances) and recall metrics (total amount of relevant instances).

The approach changes document term vectors through ontology definition, document analysis, and semantic enrichment modules. The document analysis module is responsible for extracting terms after receiving a set of textual documents. The RapidMiner indexing tool will construct a set of keywords and a term occurrence statistical vector. RapidMiner orders terms in a document by the importance of their occurrence. This module involves two stages which are the term extraction and term selection process. For term extraction, each document is split into sentences which are then extracted as tokens. All tokens found are transformed to lower case, and the terms that belong to the predefined stop word list will be removed. The remaining terms are then converted to their base forms, and the terms with the same stem are then combined for frequency counting. Tokens with lengths lower than four and more than fifty characters are discarded. The n-Grams generation is then applied, and for this case, unigrams, bigrams, and trigrams were considered. In the term selection process, the weight of each term in each document is calculated, and those which satisfy the minimum threshold are retained. To reduce the high dimensionality of the generated vectors and the computational power required to process the generated vector, only terms with a TF-IDF score greater than 0.001 are considered in this study. The selected terms will be compiled into a list of important terms for document set D. Thus, there is a resultant statistical vector for each document in the corpus D.

The semantic enrichment module will then alter the statistical vector using information from the domain ontology and produce the semantic vector (SV). The domain ontology was not developed from scratch but is a combination of several knowledge bases, which are the OmniClass Standards for the Construction Environment, the BuildingSmart IFD Library, and the Construction Information and Knowledge Portal ontology by applying MENTOR methodology. There are three procedures to create the SV. The first step is the keyword-based SV that only considers the relationship between terms presented in the statistical vector and the concept in the domain ontology by identifying the statistical vector keyword associated with a particular document and then looking for similarities between them and the equivalent term within the ontology. In the taxonomy-based vectors, the weights of concepts were adjusted according to the taxonomic relationships among them. If two or more related concepts appear, the existing relationship can boost the relevance of the expression and therefore enhance weighting. The taxonomy-based SV is calculated using input from the keyword-based vector. On the other hand, the creation of

ontological-based SV involves using taxonomy-based SV as an input comprising two stages. The first stage boosts concepts weight presented in the taxonomy-based vector depending on the ontology relation. In contrast, new concepts not present in the input vector were added according to ontological relations they might have at the second stage. The new concept is only added to the vector if the importance of an ontological relation exceeds a pre-defined threshold.

The system prototype consists of three layers: the knowledge repository layer, service layer, and user interface layer. The knowledge source is uploaded through the document repository portal. After each successful upload, a corresponding set of vectors will be stored in the Semantic Enrichment of Knowledge Sources (SEKS) database. Users can also navigate through the domain ontology and search for a document. The service layer is responsible for all calculus needed to create semantic vectors associated with each knowledge source and calculate the similarities between the user query and vector.

A dataset focused on related products used in the B&C domain was used for evaluation. The approach was tested on 20 scientific publications with the evaluation core aspect is to measure the effectiveness of the altered term vectors. From the evaluation, the researcher concludes that there is an improvement in the recall metric using their approach.

C. ONTOLOGY-BASED KNOWLEDGE SHARING SYSTEM FOR HEALTHCARE

Bai & Guo [68] proposed an ontology-based knowledge sharing system based on the activity theory (descriptive tool for a system), providing a high-level and rich ontology for the e-health system developers. The approach was validated by demonstrating the Integrated Mobile Information System for Healthcare (IMIS) project. Different care providers in various organizations provide similar or related health services. There is a problem in knowledge sharing as these organizations use different vocabulary, concepts, and models. Thus, e-health system developers need to find a strategy to deal with these diversities.

Electronic Health Record (EHR) is the most discussed knowledge in e-health containing clinical information stored in structured and unstructured documents and various formats. The EHR stores electronic history record that is important for future reference to health care practitioners for clinical decision making. The challenge that healthcare providers face when implementing knowledge sharing is having access to distributed clinical information at any time and from any location. Access to various ICT tools is also necessary to facilitate consultation between the doctor and the patient.

Activity theory has become a focal point for system developers. In this paper, the researcher uses activity theory as a framework to develop a knowledge-sharing ontology for healthcare systems. The activity theory consists of the subject-instrument-object-outcome relationship.

The IMIS was developed to integrate healthcare providers and healthcare receivers into web-based and mobile platforms to increase interoperability, integrity, and mobility. The focus of IMIS is the construction of intelligent monitoring and alarm system based on the ontology of the activity theory model. The system integrates care providers and care receivers based on the activity model that the two are inseparable. Users can define their specific roles as care providers or care receivers through the registration interface. After validation by certification management, the user's role will determine which information is relevant and what user interface should be used. In this system, users can retrieve relevant contact information as there is a need to share information and responsibility about the targeted object, such as knowing former work and keeping track of some happening in work shift situations.

Overall, we can summarize that this paper proposed an ontology-based knowledge-sharing system for healthcare services. The idea is that healthcare providers (such as hospital care, primary care, etc.) and healthcare receivers increase interoperability, integrity, and mobility. The knowledge (ontology) concerns the healthcare activity based on Engstrom's activity theory model. The knowledge to be shared is the Electronic Health Record (EHR).

D. ONTOLOGY-BASED SYSTEM FOR TUJIA BROCADE

Zhao *et al.* [69] proposed a Tujia brocade (Chinese handicraft) knowledge-based system based on an ontological approach. The researchers tried to solve the issue of ununified resource extraction standards and ineffective resource organization and semantic connotation.

The knowledge-based system comprises of data, service, and presentation layer. The presentation layer is responsible for providing an interface for user access. Ordinary users can learn Tujia brocade knowledge through the knowledge-based portal, while an expert user will have special rights to log in and manage the knowledge-based system. The service layer is the system core layer responsible for resource annotation, knowledge management, knowledge retrieval, and user login and registration. This layer receives data from the presentation layer and feeds the result set to the presentation layer. This layer also realizes the read and write between data layers. The third layer is the data layer that combines the resource library, ontology library, and index database. This layer is responsible for the data storage of the knowledge base of the Tujia brocade domain.

The formal definition of Tujia brocade metadata specification is based on the analysis of Tujia brocade domain knowledge based on the Dublin Core metadata and the learning object meta-model. The specification has 15 core data sets and 36 Tujia brocade elements. The semantic annotation module connects the resources and knowledge domain and creates the Tujia brocade semantic knowledge. The first step in the process is to extract characteristics of various types of Tujia brocade culture resources, such as brocade pattern size, color matching, and storage formats. Then, to match the

annotation, the concept of the domain ontology associated with the resource is embedded. Finally, a semantic annotation index document is generated.

The Tujia brocade domain ontology is built using the iterative seven-step process. By analyzing the knowledge domain, the attribute and relationship are determined. Referring to relevant literature and consulting Tujia brocade expert, the Tujia brocade knowledge were analyzed, and the boundary was determined. The ontology was validated using Protlet, which is the extension of the Pellet reasoner plugin, to detect logical errors.

The Tujia brocade design guides the realization of the annotation function knowledge-based system, which realizes the semantic association between the resources library and the ontology library. The annotation covers the formal title, title alias, keyword, content, and other Tujia brocade metadata. A knowledge map was used to show the inter-relationship among the resources so that users can have an intuitive and clear knowledge structure. The knowledge retrieval module combines full-text and semantic retrieval. When a user enters a query statement, the query conditions go through a series of processing. The relevant knowledge of the search is displayed in the form of a knowledge map.

E. ONTOLOGY-BASED KNOWLEDGE-BASED SYSTEM FOR DECISION MAKING

Jelokhani-Niaraki [23] proposed a web-based Multi-criteria Spatial Decision Support System (MC-SDSS) to aid knowledge sharing between decision-makers during decision-making processes. The proposal was based on the situation, which shows that the web-based GIS-MCDA system lacks a knowledge-sharing mechanism and framework. Because decision knowledge exchange relies on individual common sense to interpret the meaning of each other's knowledge, an ontology was proposed to overcome this limitation by providing automatic interpretation mechanisms.

Effective knowledge sharing among decision-makers, such as urban planners, experts, and analysts, may provide a collective solution during spatial decision-making processes. The approach integrates several components into a single system, including the GIS, MCDA, web, agent, and people. The GIS-MCDA ontology is the system's core to facilitate the communication between agents who act on behalf of decision-makers and mediators by providing a common and shared understanding of the knowledge term. There are five stages in the knowledge sharing and decision-making workflow. The process starts with each decision-maker specifying their decision model (elements). Then the decision makers' agents exchange and share their knowledge elements based on the ontology and followed by each decision maker complete knowledge sharing to form their decision model. Relevant GIS and MCDA tools were utilised to compute criteria values and obtain individual solutions based on the model. Finally, the individual decision maps are aggregated to obtain a group solution using a group decision rule. The collaborative GIS-MCDA ontology provides a decision knowledge

skeleton derived from decision makers' knowledge elements. The ontology unifies the domain knowledge of the GIS, MCDA, and collaborative decision-making research areas. In this system, decision-makers store their knowledge as instances of ontology classes that form the knowledge base used by agents for knowledge-sharing purposes.

The target user of the prototype is urban planners with different expertise levels and knowledge abilities. The human mediator initializes and specifies the decision domain and invites the urban planners to participate. The invitation can be done according to their expertise, age, education, or voluntarily. Initially, the knowledge base contains knowledge collected from expert urban planners or other sources. It evolves during the participation process by the new domain-specific decision knowledge elements created or shared by the urban planners. The human mediator is also responsible for verifying the knowledge elements by adapting a manual mechanism to ensure the quality and reliability of the knowledge before being incorporated into the knowledge base.

Decision-makers input their decision knowledge by specifying the objectives, sub-objectives, constraints, alternatives, and preferences. Once the individual decision knowledge model is created, the system stores them in the ontology. This knowledge then can be queried for lexical and context similarity analysis via the knowledge matcher module of the knowledge sharing process. The participant can request knowledge through a mediator agent using a message. The request is interpreted once the mediator receives the message, and the corresponding knowledge is returned based on the similarity assessment. In the case of diverging opinions by knowledge providers, the mediator agents rank the knowledge elements according to their expertise level. The one with the highest level is selected and returned to the novice user.

Novice users, however, can examine all the suggested knowledge and synthesize them to make a combined knowledge element. Once the participant completes the knowledge-sharing process, their decision models can be created. The GIS tool performs constraints analysis to identify the set of feasible alternatives and attributes value analysis to determine the value of the attribute associated with the alternatives based on the constraints and attributes specified in the individual models. The GIS tool then sends the feasible alternatives and the attribute's value to the MCDA tool, determining the alternative locations' scores or rankings. Finally, the individual maps can be combined to calculate the group solution.

F. ONTOLOGY-BASED KNOWLEDGE SHARING SYSTEM FOR ECONOMICS

Yoo & No [70] use semantic web technologies to enhance economics knowledge sharing on the verified research and analyses of economic phenomena. To generate the knowledge, economists applied a three-step process: modeling the economic phenomenon, specifying the model variable, and verifying the model by analyzing corresponding data. Instrumental Variables (IV), which is vital to identify precise causal inferences, can be determined using a systematic and efficient

knowledge-sharing approach. Economic knowledge sharing ontology (EKSO) and a knowledge-sharing system, called the Ontology-Based Economics Knowledge Sharing System (OEKSS), were created to aid the process.

The registration, ontology, data storage, reasoning, and economics knowledge sharing layers comprise the architecture of OEKSS. The ontology was built using the method proposed by Noy & McGuinness. The knowledge was collected from online documents such as published papers, proceedings, and books which were then used to decide the main concepts of EKSO. The EKSO is stored in the ontology layer, domain rules, and economics variable cloud. Through the web-based registration interface in the registration layer, users can input information relating to the economics documents such as the metadata, scope of knowledge, definition of variables, and relationships between the variables.

The economics variable cloud contains user-defined variable sets with two functions: variable suggestion and visualization. When a user enters an upper variable, the system will suggest a list of potential variables based on simple text matching. In contrast, the system will provide a visual representation for variable visualization, and their importance is reflected from the font size. The data storage layer consists of the system and semantic data, which contain the data required for system operation as well as economic knowledge in the form of a triple structure. When the reasoning engine creates inferred knowledge, the reasoning layer will add the knowledge to the semantic data layer. The economics knowledge sharing layer provides three functions: the basic search, knowledge navigation, and instrumental variables (IV) recommendations. The primary search function uses a simple triple pattern matching service. At the same time, knowledge navigation supports the visualization service of economics knowledge. The IV recommendation will present suggestions on IV for independent and dependent variables according to a user request. The IV recommendation uses the instrumental variables recommendation algorithm (IVRA) by utilizing the EKSO.

G. ONTOLOGY-BASED CLOUD KNOWLEDGE MANAGEMENT SYSTEM FOR EDUCATIONAL

Mohammad Amine Mostefai *et al.* [71] proposed a cloud computing environment for the educational knowledge management system. The idea is based on a current conventional approach that requires the utilization of expensive Information Technology (IT) infrastructures. The Knowledge Management System Agile Implementation Methodology (KMSAIM) was adopted for project execution. The initialization phase of this methodology is followed by four sub-phases: domain mapping, profiles and policies, implementation and personalization, and validation. The objective of the initialization phase is to gain an understanding of the organization, the corporate knowledge, the knowledge flows, and the business concepts through the interaction with the client, user, and business domain. New concepts are captured

in the domain mapping phase, and existing concepts are updated.

In contrast, the profiles and policies phase were responsible for assigning authorization scope and determining user access privileges for each profile. The implementation and personalization phase transforms the requirements into functional modules based on the concepts captured during previous phases. Finally, the implementation team will validate the system during the validation phase to ensure it is working as expected and fulfilling the requirements.

The main objective of the case study project is to collect educational material which allows teacher integration and resources annotation by both teachers and students. Collaboration is also necessary for teachers to interact efficiently to develop and manage educational resources. The system was designed using .Net technologies on Microsoft's cloud-based platform of Windows Azure. Learning Object Metadata (LOM) was utilized to create the ontology in this research.

The Knowledge Management System (KMS) has five functional modules: meta-data, knowledge base, collaboration service, personalization service, and security service. The meta-data layer maps the ontology in the database schema. In contrast, the knowledge base layer manages the storage and retrieval of knowledge assets such as learning resources, questions, and authors. The collaboration service allows users to communicate and interact through forums and annotations, whereas the personalization service customizes the screen and forms based on the existing user profiles. On the other hand, the security service is in charge of setting user access levels and actions and authenticating memberships.

The system's architecture comprises six technical layers: the cloud infrastructure, .Net framework, database, web server, KMS services, and client. The cloud PaaS system is the cloud infrastructure, while the .Net framework serves as the foundation for various KMS modules and services. The KMS material was stored in the database layer, while the individual KMS modules were housed in the KMS service layer. The final layer, the client layer, is a web browser that the end-user uses.

H. ONTOLOGY-BASED KNOWLEDGE SYSTEM FOR HELICOPTER TRANSMISSION DESIGN

Zhao *et al.* [72] develop a knowledge system for helicopter transmission design knowledge. The system was created to assist designers in gathering related knowledge from various sources, particularly tacit knowledge held in another designer's memory.

Distinct features were provided for different user roles, and the system's design was divided into three layers: function, data, and hardware. The knowledge management, knowledge retrieval, model management, and user management modules make up the function layer, whereas the data layer manages the function base, behavior base, structure base, and model base. Servers, databases, and network devices are used in the physical layer.

The process started with the knowledge managers annotating the design knowledge into the system through the knowledge management interface. The knowledge is then stored as an ontology in the ontology database. Aside from that, the knowledge retrieval operation can be carried out via a web application named the knowledge retrieval interface. The designer can then use the system to discover instances and classes that are interrelated.

I. ONTOLOGY-BASED KNOWLEDGE MANAGEMENT SYSTEM FOR DIGITAL HIGHWAY CONSTRUCTION INSPECTION

Xu *et al.* [73] suggested a strategy to address the shortage of highway construction inspectors. The proposed approach should retain and manage highway construction inspection knowledge such as what, when, and how to conduct inspections while integrating them into the construction business process. The source of knowledge for developing the ontology comprises both tacit and explicit knowledge, which is collected from Indiana Department of Transport (INDOT) inspection documents and by a discussion with INDOT experts.

The systems developed are specific to highway construction inspection, and the system architecture comprises three layers: data, knowledge, and application. The data layer consists of unstructured data for inspection information extraction and conceptualization, including the INDOT standard specification, risk-based prioritized activity list, inspection check items, pay items, and QA documents. In the knowledge layer, data from the data layer were extracted to form an inspection knowledge base and encoded into Web Ontology Language (OWL) format. Finally, the application layer, which is the digital inspection system, was equipped with five modules that are the generation of risk-based prioritized inspection activities, generation of inspection activity-centered pay items, generation of pay item-centered check items, generation of check details that include check priority, frequency, object, attribute, and acceptance criteria, and documentation checking, and storage of inspection data. The system can generate real-time inspection forms to support the inspection activities aligned with the construction progress.

J. ONTOLOGY-BASED DECISION SUPPORT SYSTEM FOR DOMESTIC SOLAR HOT WATER SYSTEMS SELECTION

Kontopoulos *et al.* [74] highlighted the need to select domestic solar hot water systems tailored to consumers' preferences, especially non-technical users. Using an ontology, the system can suggest relevant results based on the parameters input by the user, which are the number of occupants, water volume per person, and location. SPARQL queries were used to match the input parameters to the system configurations during this process.

The researcher extends the Urban Energy System (UES) ontology by adding additional classes using Noy and McGuinness methodology in terms of ontology development.

The ontologies then were submitted to OOPS! for checking on common pitfalls.

The system architecture comprises the front end, a server, and a back-end component. The front-end component will provide a user interface to enter the system's initial input and retrieve the results. Instead, the back-end component houses the ontology together with Jena and SPARQL modules and CSV files. The Apache Tomcat server realizes the communication between both components.

K. ONTOLOGICAL KNOWLEDGE-BASED DECISION SUPPORT SYSTEM FOR PATIENT FOLLOW-UP ASSESSMENT

Zhang *et al.* [75] applied the ontology approach to developing a knowledge-based decision support system. The system was developed to improve patient follow-up services' accessibility, efficiency, and quality. For full accessibility and seamless integration, the system was deployed on both personal computer and mobile platforms.

The system architecture consists of three layers: the knowledge, service, and application layers. The knowledge layer, which is the ontology-based framework, contains patient semantic healthcare records, domain knowledge-base, and assessment knowledge base. Virtual Medical Record (vMR) ontology was built by transforming data records of type 2 diabetic patients into instances. The knowledge-based domain comprises 544 terms related to type 2 diabetes from the combination of 20 diseases, 84 examinations, 120 symptoms, 122 drugs, 34 physical exercises, and 164 kinds of food. At the same time, 19 assessment models under different clinical conditions were defined in assessment knowledge-based.

L. ONTOLOGY-BASED DECISION SUPPORT SYSTEM FOR SAFETY RISK IDENTIFICATION

Xing *et al.* [76] developed an automatic recognition system for the construction safety risk of the metro project (MRARS). The system aims to formalize safety risk knowledge in metro construction to identify safety risks.

The Safety Risk Identification ontology (SRI-Onto) was created by extracting and formalizing domain knowledge from various sources such as relevant regulations, case sets with related research reports, related research work, existing similar system platforms, and expert seminar conclusions. Five steps methods were applied to the ontology building process. The ontology validation involved two processes: using Pellet reasoner for inconsistencies assessment and evaluation by domain experts and engineering practitioners through a seminar.

The system component comprises of knowledge base management subsystem and a risk reasoning subsystem integrated with Safety Risk Identification ontology (SRI-Onto). The knowledge base management subsystem is responsible for fact-based management, rule-based management, and case base management. The function of fact base management is to describe knowledge on safety risks of the metro project.

In contrast, rule-based management describes the reasoning rules for safety risk knowledge, and case base management is meant to describe the existing case.

The system allows users to access knowledge by inputting pertinent engineering data from a real-world metro project. Through assessing construction specifications and risk reasoning, potential safety concerns will be identified. Furthermore, similar risk instances can be extracted from the case database as references.

M. ONTOLOGY-BASED MULTI-AGENT MANAGEMENT SYSTEM FOR SMART SCHOOL MANAGEMENT

Samia, Khaled & Warda [77] designed a multi-agent management system to facilitate information integration and knowledge sharing between heterogeneous knowledge and information sources in smart schools by using the ontology approach.

The ontologies were structured according to abstract entities commonly used in school. The example of the entities is objective, presence, lesson, and classroom. The objective entity corresponds to Bloom's taxonomy's six levels of mental processing, which were used to determine instructional objectives. In contrast, the presence entity was utilized to gather and analyze attendance knowledge.

Eight kinds of agents were designed as a component of the system: the presence, teacher, class, mobile, supervisor, ontology, administrator, and interface agent. These agents communicate and collaborate, and each agent has its own set of knowledge. The presence agent is responsible for collecting and capturing attendance data from the monitor located in the classroom by capturing management frames transmitted by students and the teacher's device. The agent will extract MAC user addresses in management frames before filtering them into an attendance list. A teacher agent must oversee all teaching and pedagogy operations to concentrate on improving teaching and saving time. This agent displays results to teachers by interacting with the interface agent. Meanwhile, the class agent will coordinate tasks between the presence, teacher, and mobile agent by receiving attendance information from the presence agent, sending it out to the teacher agent, and providing the list to the mobile agent.

The task of a mobile agent is to explore the school network to collect data by moving from nodes to nodes that correspond to different classrooms. The supervisor agent is used to manage the mobile agent and pass the information collected by a mobile agent to the administrator, while the ontology agent will perform the ontology management of learning content and school management by storing information received from the administrator. The ontology agent also responds to requests by the administrator and updates the ontology when needed.

The administrator agent is in charge of keeping track of each teacher's lesson plan and making administrative decisions based on the supervisor agent's findings. It can provide parents with information about their children's attendance and other essential school activities and generate reports.

The last agent is the interface agent, allowing teachers and administrators to interact with the system by sending requests and viewing results. It is also responsible for ensuring that each user receives the display intended for them.

IX. DISCUSSION

Thirteen articles on ontology-based knowledge management solutions were studied to identify the elements and approaches used to facilitate knowledge-sharing activities in organizations. Follows are the discussion based on the comparison criteria previously defined.

A. MOTIVATION

The primary goal of all the tools examined is to aid users in gathering and sharing information. Multiple approaches were utilized to improve the way users store and retrieve knowledge, such as developing an integrated system and applying an ontology to the system. Several tools [67], [73] also explore the idea of sharing the document that contains the required knowledge in addition to sharing knowledge itself.

The researchers also attempt to improve the process of knowledge creation, which includes providing a suitable environment for the users, such as by using a cloud-based system and adapting a mobile platform. Finally, we can see that the main goal is to improve organizational knowledge management, especially in terms of information exchange. This has demonstrated that the primary goal of developing ontology-based KM tools is to effectively implement knowledge-sharing activities.

B. DOMAIN

The reviewed tools revealed a variety of knowledge domains that exist in the organization. The studies and tools were designed to solve a specific problem that emerged in the researchers' organization. Thus some variation is to be expected. Only two articles focus their research on the generic knowledge domain, while the rest tackle specific domains such as economics, software testing, health, and education. Focusing on specific domains limits the extensibility of the tools. Thus, more research is required to make these tools applicable to multiple domains.

C. SOURCE OF KNOWLEDGE

Human is the most important source of knowledge, as revealed by the reviewed paper. Such a finding is unsurprising given that most of the articles reviewed focus on facilitating knowledge-sharing activities amongst organization members. Aside from humans, most research focused on knowledge sources in written materials such as documents and articles. Videos were also addressed in the tools that were examined. In the future, it might be worthwhile to investigate a broader range of knowledge sources, such as web content, social media posts, and messaging apps (WhatsApp and Telegram).

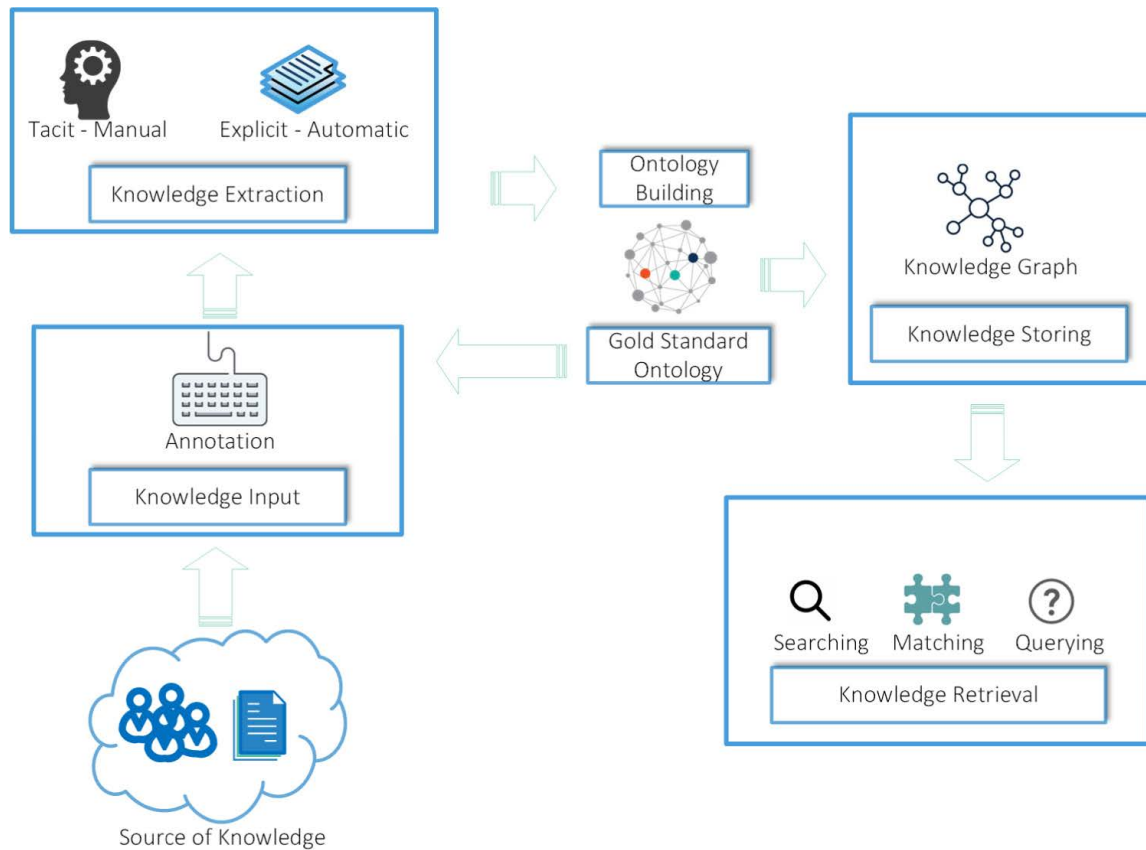


FIGURE 3. The concept of an ideal ontology-based knowledge management tools component and function.

D. TYPES OF KNOWLEDGE

This review focuses only on the difference between tacit and explicit knowledge. It was found that most articles and technologies focused on handling explicit knowledge, except for the work by Xu *et al.* [74] and Xing *et al.* [77] which covers both explicit and tacit knowledge. Most of the technologies tried to solve the issue of knowledge creation and, more importantly, knowledge sharing, which requires information to be transmitted from one person to another. The integration of tacit and explicit knowledge may be further explored since this approach significantly affects knowledge sharing implementation in organizations.

E. KNOWLEDGE EXTRACTION

Extracting knowledge from unstructured data is regarded as the most challenging task [78]. The extraction of knowledge can be done manually or automatically. We discovered only a single tool that uses a RapidMiner to extract information from a knowledge source, which could be considered an automated knowledge extraction technique. In contrast, the rest of the applications required users to manually input knowledge through the system interface. The automated knowledge extraction method may be further investigated so that the system's features can be customized to the user's needs, resulting in a more efficient knowledge management process.

F. KNOWLEDGE INPUT PROCESS

The most popular approach observed for the knowledge input process is the annotation by users. Users annotate knowledge into the system before being processed and made available to others. A mechanism is also implemented that enables users to submit knowledge material such as papers and videos. This procedure should be investigated thoroughly to enhance the operation by simplifying and automating the input process.

G. KNOWLEDGE RETRIEVAL PROCESS

Knowledge retrieval aims to return information in an organized format that is congruent with human cognitive processes. Most tools use a simple search function to access and retrieve the required knowledge. Since the volume of knowledge in the system is often enormous, this function will assist the query process by using a matching procedure. Although direct access to the system's knowledge content is possible, albeit to its simplicity, the search function seems to be a practical and effective method of retrieving relevant information accurate and timely manner. Other methods of obtaining knowledge from the system may be further investigated in order to improve user experience using the tools.

H. KNOWLEDGE SHARING TECHNOLOGY

A lot of technologies can be adopted in managing knowledge in organizations. Researchers experimented with different

TABLE 3. Review summary.

Reference	Motivation	Domain	Source of Knowledge	Type of Knowledge	Knowledge Extraction	Knowledge Input Process	Knowledge Retrieval Process	Knowledge Sharing Technology	Source of Ontology Component	Ontology Methodology
Vasanthapriyan, [22]	To assist software testers to get information on software testing methods and software development model	Software Testing	(Human) User experience in performing software testing	Tacit	Manually Input	(Annotation) Software testers annotate testing knowledge through the system interface with the aid of ontology	(Searching) Knowledge was retrieved using a simple triple pattern matching service (SPARQL)	Ontology and Knowledge Sharing Portal	Concept defined from IEEE 829-2008 and ISTQB (International Software Testing Qualifications Board) Domain extracted from existing literature and interviewed the software testing experts	Gruninger and Fox
R. Costa et al. [67]	To formalize and represent document content Introduce a conceptual framework for knowledge representation of knowledge sources, where each knowledge source is semantically represented	Building and Construction	(Document) Textual Document	(Explicit) Integrated project data Historical project information	(Automatic) RapidMiner order term in a document by the importance of their occurrence	(Upload/Semantic Indexing) Knowledge/document upload to repository Documents are indexed and semantically matched with the ontology	(Searching) User navigate and search document	Ontology and Knowledge Repository	A combination of several knowledge-based which is the OmniClass Standards for the Construction Environment, the BuildingSmart IFD Library, and the Construction Information and Knowledge Portal ontology	MENTOR
Bai and Guo [68]	To provide high level and rich ontology for the e-health system developer	e-Health	Based on Activity Theory Model	(Explicit) Healthcare Activity	(Manual) Identifying knowledge using activity theory model	(Annotation) User input knowledge to the system	(Searching) User access knowledge from the system	Ontology and Knowledge Sharing System	Adaptation of Activity Theory Model	Using Activity Theory Model
Zhao et al. [69]	To unified resource extraction standards To improve the effectiveness of resources organization and semantic connotation.	Tujia Brocade (Chinese Handicraft)	(Human)	(Explicit) Design of Tujia Brocade	Manually Input	(Annotation) User annotate through knowledge base system interface	(Querying) User query terms are matched with the ontology concept as well as the full text index. Match search results are presented in knowledge map.	Ontology and Knowledge-Based System	Field research, referring relevant literature and consulting Tujia brocade expert	Seven Step Method
Jelokhani-Niaraki [23]	To support exchange and sharing of decision knowledge between decision makers (urban planners)	Geographic Information	(Human) Decision Maker Knowledge	Tacit	Manually Input	(Annotation) Decision makers input decision knowledge into the system	(Requesting) Participant agent request knowledge from the mediator agent through the system	Ontology and Knowledge-Based Decision Support System	Decision Maker's knowledge	Not Describe
Yoo and No [70]	To share economic documents and variables information	Economics	(Human) User knowledge of economics document metadata and economics variables	Explicit	Manually Input	(Annotation) User input metadata and variables information through the system interface	(Searching) Users find document and variables information through a basic search function.	Ontology and KS Portal	Concept defines from published papers, proceedings, and books	Noy & McGuinness methodology
Mohammed Amine Mostefai et al. [71]	To collect educational material for teacher integration and the annotation of resources by	Educational Resources	(Human) Educational Resources	Explicit	Manually Input	(Annotation) User annotate educational resources to the system	(Searching) Users access educational resources using the web browser	Ontology and Knowledge Management System	Learning Object Metadata (LOM)	Not Describe

TABLE 3. (Continued.) Review summary.

	teachers and students									
Zhao et al. [72]	To help designers to gather and acquire helicopter transmission design knowledge	Helicopter Transmission Design	(Human) Helicopter Transmission Design	Tacit	Manually Input	(Annotation) Knowledge managers create the ontology knowledge (KM interface) and add files (model management)	(Searching) Designers use knowledge retrieval interface to search interested instances or classes	Ontology and Knowledge System	Based on knowledge categories comes from different design stages	Not Describe
Xu et al. [73]	To retain and manage construction inspection knowledge (what, when, and how to inspect) and integrate with the construction business process	Highway Construction Inspection	(Documents and Experts) Highway Construction Inspection	Tacit and Explicit	Not Describe	Not Describe	Not Describe	Ontology and Knowledge-Based System	Inspection documents and discussions with experts	Not Describe
Kontopoulos et al. [74]	To provide information and facilitate consumers on the selection of domestic solar hot water system	Domestic Solar Hot Water Systems	(Dataset) Urban Energy System (UES) ontology extended with additional ontology	Explicit	Manually Input	(Annotation) User filled up a number of occupants, water volume per person and location	(Matching) Appropriate results based on the input will be shown	Ontology and Decision Support System	Urban Energy System (UES) ontology extended with additional classes	Noy and McGuinness
Zhang et al. [75]	To develop knowledge-based system for patient follow-up assessments	Chronic Disease	Integration of knowledge from knowledge acquisition process with Virtual Medical Record (vMR) ontology	Explicit	Not Describe	Not Describe	(Requesting) Case manager request an assessment service	Ontology and Knowledge-Based Decision Support System	Patient healthcare record	Not Describe
Xing et al. [76]	To formalize safety risk knowledge in metro construction to support safety risk identification	Safety Risk Identification	Domain expert and related documents (Ontology)	Tacit and Explicit	Manually Input	(Annotation) Engineering information was input to the MRARS through related choice questions or unformed data form guided by SRI-onto	(Searching) Detailed project information of cases searched in the case base	Ontology and Decision Support System	Standards and technical manuals, case set with related risk research reports, and existing research and system platforms	Five Step Methods
Samia, Khaled, and Warda [77]	To facilitate information integration and knowledge sharing in smart school	School Management	School Abstract Entities (Ontology)	Explicit	Not Describe	Not Describe	(Querying) The user sent a query to a related agent through the interface agent	Ontology and Management System	Structured by a set of abstract entities specially used in school	Not Describe

types of technologies that might help in the procedure. The most widely investigated technology is the knowledge base system, which is then integrated with other technologies, such as ontology. Ontology has been identified to be a useful semantic technology for knowledge management, particularly concerning knowledge sharing. Apart from that, the effectiveness of knowledge sharing and management systems were investigated. The integration of ontology with mobile apps may be relevant to future research, given its importance as a medium for information exchange nowadays.

I. SOURCE OF ONTOLOGY

The reviewed tools used various materials as their ontology sources. In [22], knowledge was collected from the experts to build the ontology. Knowledge was also gleaned from printed papers and literature. Some researchers also utilized an ontology based on specific knowledge frameworks such as the Activity Theory Model adaptation. These results indicate that more knowledge sources may be explored and manipulated in the future to construct the ontology.

J. ONTOLOGY BUILDING METHODOLOGY

Specific methodologies may be used to construct various ontologies. A particular method that provides a set of guidelines is required to build a domain ontology. [79]. Although not all articles describe the technique used, some valuable information can be observed. The Gruninger and Fox [22], MENTOR [67], seven-step technique [69], and Noy&McGuinness [70], [74] methodologies were all utilized to construct the ontology. A mixed-method may be tested in the future to evaluate whether they are suitable for creating an ontology.

X. THE CONCEPT OF IDEAL ONTOLOGY-BASED KNOWLEDGE MANAGEMENT TOOLS COMPONENT AND PROCESS

Figure 3 shows the concept of an ideal ontology-based knowledge management tools component and function. In this diagram, the source of knowledge is the starting point to implement knowledge sharing in an organization by utilizing ontology-based knowledge management tools and technologies. We viewed that human-derived knowledge and printed materials are the two most significant sources of knowledge.

As a first step, the knowledge must be input into the KM tool. Several different approaches may be employed to manage the process of inputting knowledge. As exhibited by most of the reviewed papers, annotation is among the process required while uploading knowledge into the tool. In general, annotation is the process of adding value to existing objects without actually changing them. In the case of knowledge-sharing tools, it allows users to add explanations or ‘meanings’ to essential concepts of the knowledge sources. The annotation can be guided by employing a gold standard ontology, which is a previously constructed reference ontology accepted by experts in the domain [80]. The concept in the gold standard ontology that domain expert has validated may be used as a reference resource in the annotation process.

Annotated knowledge sources then undergo a knowledge extraction procedure. Knowledge extraction is the creation of knowledge from structured or unstructured sources. From the review, this process’s output can be in the form of machine-readable or machine unreadable formats. However, the machine-readable and machine-interpretable format is highly desirable as it will automate future processes. At this stage, the type of knowledge will determine the extraction method to be applied. Tacit knowledge is often extracted manually and explicit knowledge, on the other hand, is extracted automatically using software such as text extraction applications. The extracted token can be manipulated and used to construct related and valuable ontology. With all associating metadata, this ontology must now be stored to be shared later. Such machine-readable knowledge can be stored in various formats. However, the current standard and technology suggest a knowledge graph as a preferable format [81].

Well-structured knowledge can be queried and retrieved via a knowledge retrieval component. The component

involves action by users to access the stored knowledge. Several techniques can be applied in accessing the knowledge, and the most frequent and ideal technique is by using searching, matching, and querying functions. The retrieved knowledge can now be used and manipulated by the user.

XI. CONCLUSION

As mentioned earlier, this article aims to provide direction for future research on ontology-based KM tools by reviewing thirteen representatives ontology-based KM tools. The review was carried out using a ten-element comparison criterion. The review and analysis results revealed the following fruitful research directions.

- When it comes to knowledge, most of the tools examined concentrated on a very specific and narrow domain of knowledge. As a result, it limits the interoperability of tools in different domains that share some fundamental characteristics. Thus, allowing such tools to operate in more diverse domains is essential for future research.
- Humans are the primary sources of knowledge. Only a few tools are available to help extract knowledge from various implicit sources such as articles, web documents, and operating procedure documents. Let alone discussion on various social media platforms and messaging applications. One can conjecture that some knowledge was left untraced somewhere within such a massive content. Thus, finding and extracting such knowledge that is unclassified, dispersed, disorganized, uncertain, partial, and possibly incorrect is interesting but extremely difficult [82].
- Another potential future research direction is to automate the process of creating the ontology. As knowledge evolves, it is highly desirable to keep the tool’s knowledge base up to date with new information.
- In terms of platform, applying the notion of knowledge sharing to a mobile application is also a fascinating topic to explore.
- Providing and retrieving knowledge into and from a KM tool’s knowledge base is usually a complex process for a novice non-technical user. However, none of the tools reviewed proposed promising solutions to address such an issue. Therefore, more non-formal ways of providing knowledge, such as the story-telling [83] approach, may be considered in the near future.

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