Using Ontology for Design Information and Knowledge Management: A Critical Review

Y. Liu and S.C.J. Lim

Abstract Ontology has been identified as a feasible modeling solution for rich design information and knowledge representation. From previous studies, the applications of ontology in design engineering have shown promising progress. This chapter provides a critical review of the recent achievements in utilizing ontology for design information and knowledge management. The applications of ontology in the three major categories are explicitly discussed. Most importantly, a number of research issues concerning the application of ontology in design engineering have been identified and suggested. Finally, based on the current state of research, a few promising future research directions are also briefly discussed.

Keywords Ontology · Design information · Knowledge management

1 Introduction

In today's design engineering scenario, both design and manufacturing companies are constantly investigating ways to offer better products in different aspects such as cost and product performance in order to meet with different customer expectations. The ever changing customer tastes on product requirements have forced design and manufacturing companies to offer more product choices that target at different market segments. Taking the amount of design information generated during the design process into consideration, the management of design information and knowledge has become a critical issue worth investigating. Design information refers to information generated during the design of an artifact, such as artifact associated design specifications, functions, materials and manufacturing process. This information are usually recorded in design documents, that may include design proposals, final design drawings and engineers' logbook, handbooks, patent documents, online catalogs or magazines. With the advent of computerized design tools and database system, the challenge lies in processing these large amounts of information in order to effectively and efficiently capture, index, store and retrieve them, as well as to discover meaningful knowledge for timely decision making.

For the majority of design and manufacturing organizations, design information and knowledge are regarded as an important asset for the production and delivery of their products or services, where it also plays an important role in maintaining the sustainability of organizations [1]. Advances in information communication and technology (ICT) and the realization of more affordable and powerful computers have revolutionized how design information is being created, indexed, stored and retrieved. From a previous study, it is discovered that design engineers often sought solutions from past design cases in solving their design problems where they spent 20% to 30% of their time retrieving and communicating design information [2]. Besides the issues involved in performing search and retrieval operations, a design representation that enables designers to look at design knowledge at different perspectives, either in new or unfamiliar design situations is equally important [1]. Ahmed and Wallace [3] found that in their studies involving 633 queries, novice engineers were only aware of what they needed to know in only 35% of all queries compared to experienced designers. Their findings suggest that a design representation that supports both experienced and novice designers in identifying key information during the design query process is crucial. In another study, it is revealed that a typical manufacturing organizations can have 7–12 information systems (IS) that are tailored for different needs [4]. However, these IS usually differ in terms of technologies, standards and underlying information architecture, causing expensive operations on information exchange and integration at later stages of

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design [4]. Consequently, a unified information model that allows interoperability of design information across different IS for efficient search, navigation and retrieval is essential towards streamlining the design process.

With respect to all these requirements, ontology is identified as a feasible information modeling approach that possesses rich knowledge representation capabilities for comprehensive design information and knowledge management. Ontologies are the basic building blocks of Semantic Web where it allows the mapping of information across different perspectives. Different from a taxonomic structure that describes information in a concept hierarchy manner, ontology is able to describe relationships by defining multiple semantic relationships between concepts and entities of the ontology, as well as to other ontologies. This ability allows different context of design information to be semantically modeled and new design knowledge at different perspectives to be suggested.

In the context of design engineering, there are already a substantial number of works reported that have illustrated the use of ontology in different areas of design engineering. Harnessing the semantics of ontology, the practical applications of ontology in design engineering have presented great potential in solving some of the issues of design information and knowledge management, such as better design information storage, search and retrieval; semantic interoperability for federation of design information; and intelligent product configuration. PricewaterhouseCoopers, one of the world's largest professional services firms, have recently mentioned the importance of business information context and semantics for better decision making, where they have predicted that "a transformation of enterprise data management function driven by explicit engagement with data semantics" will take place in the next 3–5 years [5]. In relation to this, we also believe that similar efforts of adding the semantic dimension in design information modeling using ontology will likely to occur given the rising interest of the design communities towards the use of ontology in recent years. Therefore, a critical review that covers the state of the art issues in development and application of ontology in design engineering is needed in order to identify possible future research directions.

This study attempts to provide a critical review on the use of ontology for design information and knowledge management. The rest of this chapter is organized as follows. In Sect. 2, we present the reviews on studies related to ontology development in design engineering. Several key applications of ontology in design engineering are comprehensively covered in Sect. 3. Section 4 discusses about the research issues surrounding various aspects of ontology applications in design engineering and some potential future applications. Section 5 concludes.

2 Ontology Modeling and Development in Design Engineering

Ontology consists of a set of concepts, axioms, and relationships that describe a domain of interest, and can be regarded as an explicit specification of a shared conceptualization, that can be taxonomically or axiomatically based [6]. In the engineering perspective, examples of concepts are "fastener" (device and structural oriented concept), "rotate" (functional oriented concept) and "plastic" (material oriented concept), that exemplifies the underlying semantics behind a domain. The concepts and relations in ontology need to be explicitly defined before its deployment in design engineering. In the area of library science or computer science, the efforts in creating ontology have started in the mid-1980s, where we witness the creation of Cyc ontology and WordNet. Cyc ontology attempts to model a comprehensive ontology of everyday common sense, and WordNet serves as a comprehensive lexical ontology for natural language processing (NLP). Later on, there are other ontologies that are built for different purposes, such as GENSIM (for genetic simulations), PLINIUS (for mechanical properties of ceramic materials) or Unified Medical Language System (UMLS) (for modeling medical concepts). A comprehensive survey and review on the design of all these ontologies are covered by Noy and Hafner [7].

In terms of ontology development, there are several early studies on the methodology for ontology development that are being proposed in the area of library science and computer science. The work by Gruber [6] is perhaps one of the earliest studies that has presented design principles for ontology development meant for knowledge sharing. Later, three most representative methodologies for building an ontology being presented: (1) Gruninger and Fox [8] proposed a methodology of designing and evaluating an ontology, that is used in developing the TOVE (Toronto Virtual Enterprise) project ontology; (2) Uschold and King [9] proposed a methodology for building enterprise ontology for enterprise modeling processes; (3) Fernandez et al. [10] presented a more systematic approach for building ontology from scratch, called METHONTOLOGY that is applied in building a chemical ontology. The review of these three methodologies can be found in Pinto and Martins' review [11]. Another notable study that serves as a useful guide in building an ontology is proposed by Noy and McGuinness [12]. Their approach to ontology engineering, named Ontology Development 101, presented a knowledge engineering approach in creating ontologies. All these studies have presented useful practical guidelines in ontology building that are adopted by researchers in the design engineering domain.

There are also other methodologies for ontology building that are specifically tailored for the design engineering domain. Ahmed et al. [13] have attempted to develop a methodology for ontology development that aimed for indexing design knowledge. Their methodology focuses on the user's domain, where they have identified four root concepts: design process, function, issue and product in their engineering design integrated taxonomy (EDIT). However, their methodology does not explicitly study the complex interrelations among the root concepts. Another methodology of building an ontology is proposed by Sarder et al. [14]. They have introduced a methodology called Domain Knowledge Acquisition Process (DKAP) for creating ontology of product and process design. Utilizing the knowledge engineering approach, DKAP presented a systematic approach in obtaining domain specific knowledge by using an ontology description form that is based on IDEF5 standard. Nanda et al. [15] applied the formal concept analysis in their methodology to develop domain specific ontology for a product family. The formal concept analysis approach is used to identify similarities among a finite set of design artifacts based on their properties and to ensure consistency in obtaining domain concept hierarchy.

From the previous literature, some of the early related works of ontology application in design engineering domain are meant for the purpose of systematizing specific domain knowledge, that includes defining and developing ontology for product configuration [16], ontology for engineering design activities [17], port ontology [18] and ontology of functional knowledge [19]. These ontologies are mostly developed based on extensive domain literature studies that aimed for representing domain specific knowledge at a higher level of abstraction for knowledge generalization. There are also some other research efforts that have modeled and evaluated ontology using empirical approaches (e.g. survey & interviews), such as the EDIT discussed earlier. The ontology developed in this way presented a more specialized area of knowledge for specific purpose, based on user needs for example that are also important towards certain domain of interest.

3 Ontology Applications in Design Engineering

This section describes some of the existing works on ontology applications in design information and knowledge management. Figure 1 illustrates an overview of ontology application in design engineering. We categorized the applications of ontology in design engineering into three major categories: (1) design information annotation, sharing and retrieval; (2) interoperability; (3) product design configuration. The detailed descriptions on each of the applications are described in the following sections.

3.1 Design Information Annotation, Sharing and Retrieval

One of the most widely preferable uses of ontology in design engineering is for the annotation, sharing and retrieval of design information. We view this area of application in two perspectives: one is where ontology functions as the underlying knowledge base to aid designers in annotation task for better retrieval, and the other one is where the ontology itself is the underlying knowledge schema for intelligent retrieval by designers and engineers. In the first perspective, ontology is used as the pre-determined and pre-defined knowledge that assists designers in annotating design information. For instance, Kitamura et al. [20] have introduced a schema named "Funnotation" for functional annotation purpose based on their functional ontology. While their annotation are accomplished using manual annotation tools, Li et al. [21] used a pre-defined engineering ontology to semi-automatically create semantic metadata of textual engineering documents. Another study by Catalano et al. [22] used a car aesthetic ontology to semi-automatically annotate two and three dimensional car models using image processing techniques. Ontology-based annotation ensures a more efficient indexing and retrieval of design information where ontology can function as the semantic indexing structure for semantic-based search and retrieval.

In the second perspective, ontology functions as knowledge base for storage of design information. Harnessing the semantic capabilities of ontology, ontology can model complex inter-relations between information, and provide users with a powerful knowledge base to complete various decision support tasks. For example, ontology can be used as functional knowledge base for functional knowledge retrieval by designers in different viewpoint [19]. In the field of engineering analysis, Groose et al. [23] used an ontology-based knowledge base named ON-TEAM to effectively share information on engineering analysis model among engineering organizations. Witherell et al. [24] studied an ontology for optimization (ONTOP) as knowledge base that can assist engineers in selecting the best engineering optimization models. Function as knowledge bases, these studies have also proposed knowledge acquisition interfaces to further populate the ontology to enable design knowledge management where additional new design cases can be effectively stored and retrieved. Lim et al. [25] have presented an information management and retrieval framework in product family design using a semantically annotated multi-facet product family ontology. By using a case study, they have demonstrated the benefits of faceted search in performing

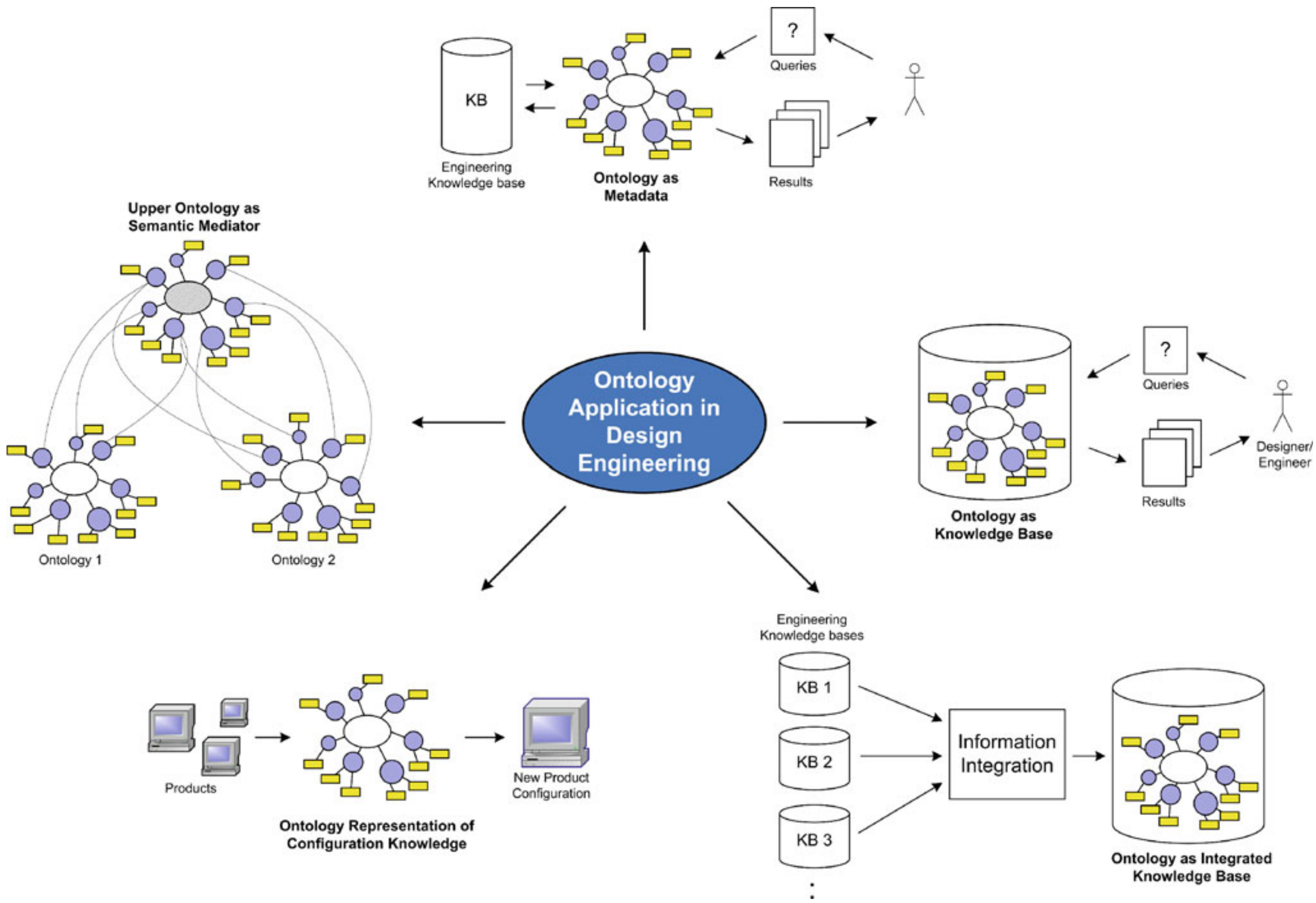

Fig. 1 Overview of ontology application in design engineering

tasks such as intelligent variants configuration and product platform search.

3.2 Interoperability

The formal conceptualization of domain knowledge embedded in ontology makes ontology useful to enable interoperability among heterogeneous knowledge base or engineering applications. Ontology in such a case is often used as a common mapping structure to achieve common understanding among different ontologies. In this context, the ontology is also commonly known with the "upper ontology" concept, where semantic ambiguities are resolved by providing common terms or vocabularies at a higher level of abstraction. An example on this topic is to apply ontology for solving the interoperability between a computer-aided design (CAD) application and computer-aided process planning (CAPP) application using feature ontology [26]. Ontology serves as a mapping mechanism to allow interchange of information across two different systems. Oh et al. [27] presented a method to enable semantic mapping of different business documents by utilizing ontology as the semantic gateway. Lin et al. [28] proposed the use of manufacturing system engineering (MSE) ontology to facilitate the semantic interoperability across extended project teams. Another study by Cho et al. [29] adopted a meta-ontology in part libraries integration where it is used for unified search among distinct part libraries. It is noted that most of these mappings between ontologies are achieved manually via specific tools.

Another stream of research in this area witnesses the use of ontology as the knowledge structure for integration of information or knowledge base. In this context, ontology can be used to integrate information sources into a unified ontological representation for information sharing. For instance, Bellatreche et al. [30] used an ontology to automatically integrate electronic catalogues to ensure consistency in data semantics. A recent study by Zhao and Liu [31] have also discussed an ontology-based methodology for encoding EXPRESS-driven product information model to web ontology language (OWL) and Semantic Web rules language (SWRL). Ye et al. [32] used a supply chain ontology (SCO) as the underlying structure for implementing semantic integration of information in supply chain applications. These studies aim to use ontology as a unified information model, and to convert design information in older ontological formats such as RDF into newer ontological representations in OWL. A good review on interoperability and information integration are discussed in a review by Ciocoiu et al. [33].

3.3 Product Design Configuration

Another important research area in design engineering where ontology is applied is product design configuration. Product configuration can be a complex process as it involves multiple aspects such as rules and constraint satisfaction. Ontology is able to model the relationships among different design artifacts of a product and offers an approach to comprehensively model the attributes, constraints and underlying design related rules for intelligent product configuration. With respect to this, an early study by Soininen et al. [16] have presented a general ontology of configuration, where detailed conceptualization of knowledge on product structures are explicitly defined. McGuiness and Wright [34] presented a conceptual modeling for configuration using description logic-based approach that focuses on the assembly process. Felfernig et al. [35] presented a configuration knowledge representations for semantic web applications using ontology languages. Most of the early works reported so far present a conceptual description on how a product configuration problem should be represented using ontology. A recent study by Yang et al. [36] have explored the use of ontology for rule-based product configuration. Different from single product configuration, ontology is also being proposed as a feasible modeling scheme to represent a product family. Nanda et al. [15] have represented a family of products using a product family ontology as a unified information structure for a product family. Lim et al. [37] have also proposed a new approach towards product analysis and variants derivation based on a semantically annotated product family ontology. Their study have shown the merits of using ontology in supporting designers for product family redesign purpose.

4 Future Research Issues and Applications

From the previous discussions on the applications of ontology, it is clear that ontology can play different roles and can be applied in design engineering in multiple ways. In such a case, explicitly defined ontologies are necessary to ensure successful deployments. However, developing ontology is a challenging task if we consider the time and efforts required. We note that majority of the ontologies are defined manually based on intensive domain literature studies, where human annotators are employed to annotate domain specific concepts and relations based on their comprehension of domain knowledge. While such an approach is essential in deriving non-trivial semantic relations and rules, the process will eventually become a burden for human annotators as the ontology evolves with incremental information. In view of the large amount of product offerings available in the market, effective means of semantic annotation for ontology development that require less human efforts is highly desirable. In this sense, the approach should be able to assist human annotators in ontology definition by providing useful suggestions for annotation. The recent trends in the field of ontology learning, with tools such as Text-to-Onto [38], and OntoLearn [39] to extract domain ontologies from corpus, can shed light on the issue of ontology development.

In relation, it has come to our attention that most of the studies do not emphasize on further updates and population of ontology. Despite the fact that a higher level ontology (e.g. upper ontology) that contains generic knowledge representation may not require much changes, other specific ontologies such as product specific component or functional ontology, user requirements ontology or marketing strategy ontology are subject to change when design information changes. This implies that the knowledge, that is once relevant, may become obsolete and new information may be discovered after the ontology has been explicitly updated. Another problem is on the annotation changes that are caused by ontological changes. The annotation on resource such as design documents or other related ontologies may no longer be valid. The dynamic updates on these annotations are also a challenging issue. To the best of our knowledge, we observe that there are still very few studies that address all these important issues. We believe that all these are important in the design engineering perspective as changes in design information will normally trigger the "chain effects" in design. For instance, the changes in upstream design activities (product specification changes) can dramatically affect the downstream design activities (manufacturing plans, packaging, supply chain, etc.). Therefore, it is desirable to study the evolution of ontological structures due to design information changes, and its impact towards the whole design process.

Another issue worth investigating is on the ontology mapping for interoperability. The mapping among ontologies is important in the aspect of integrating knowledge bases for knowledge discovery. However, the process of mapping ontologies is a challenging task. Most of the previous studies adopted a manual approach in generating the mapping between ontologies of which, in our opinion, is time consuming and tedious. For scalability, we reckon that this is an important issue as the incorporation of different aspects of ontologies, like function and manufacturing process, can be performed in a more automated fashion to enable better comparison of products. This challenge is also fundamental towards the realization of Semantic Web paradigm in the design engineering domain. We suggest the use of intelligent approaches to assess semantic relatedness between concepts, entities and properties of different ontology for semi-automated or automated mapping of ontology. A review of tools proposed for this purpose, such as GLUE, ONION and FCA-Merge, are researched in a study by Choi et al. [40].

In the ontology engineering perspective, ontology evaluation and validation is another important issue where much attention should be given. The ontology developed need to be evaluated and validated to ensure the consistency of ontology. We find that this part of research are often neglected and rarely reported in previous studies. Ensuring the validity of ontology is a complicated task that usually involves domain experts and explicit human judgments. In order to reduce human efforts and ensuring better evaluation and validation, building ontology collaboratively is one of the ways to define better upper ontology where ontologist can have a shared consensus during the process of ontology development. Web-based ontology editing tools, such as Web Protégé,[1] can be a promising starting point towards collaborative ontology evaluation and validation.

Based on the capabilities and the current trends of using ontology in design engineering, we are able to foresee a few other potential applications that are worth of investigation. Some of the potential future works include, but are not limited to, the annotations of non-textual design information such as sketches, CAD models and design animations; the representation of sequential design information such as event logs for design changes, and the cognitive aspects of design, such as design rationale, aesthetics and styling of design artifacts. All these research areas are interesting topics that await further investigation.

5 Conclusion

Ontology is identified as a feasible modeling solution for rich knowledge modeling scenarios towards comprehensive design information and knowledge management. The practical applications of ontology in design engineering have presented a great promise in the design information and knowledge management perspective. This study provides a survey on the state of the art application of ontology in design information and knowledge management. We have discussed about the methodology for ontology development that includes established guidelines proposed in library science and computer science as well as those proposed in the design information domain. We have also identified three major categories of ontology applications in design information and knowledge management: (1) design information annotation, sharing and retrieval; (2) interoperability; (3) product design configuration. The applications of ontology in the three major categories are presented. Furthermore, a number of future research issues and applications on utilizing ontology in design engineering have been critically reviewed and presented in this chapter.

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References

1. Hicks, B.J., Culley, S.J., Allen, R.D., Mullineux, G. (2002) A framework for the requirements of capturing, storing and reusing information and knowledge in engineering design. International Journal of Information Management, 22:263–280.
2. Court, A.W., Ullman, D.G., Culley, S.J. (1998) A comparison between the provision of information to engineering designers in the UK and the USA. International Journal of Information Management, 18:409–425.
3. Ahmed, S., Wallace, K.M. (2004) Understanding the knowledge needs of novice designers in the aerospace industry. Design Studies, 25:155–173.
4. Hicks, B.J., Culley, S.J., McMahon, C.A. (2006) A study of issues relating to information management across engineering SMEs. International Journal of Information Management, 26:267–289.
5. PricewaterhouseCoopers (2009) Technology Forecast: Spring 2009. PricewaterhouseCoopers International Limited, USA.
6. Gruber, T.R. (1993) Toward Principles for the Design of Ontologies Used for Knowledge Sharing. KSL 93-04, Knowledge Systems Laboratory, Stanford University.
7. Noy, N., Hafner, C. (1997) The state of the art in ontology design. AI Magazine, 18:53–74.
8. Gruninger, M., Fox, M.S. (1995) Methodology for the design and evaluation of ontologies. Proceedings of International Joint Conference of Artificial Intelligence Workshop on Basic Ontological Issues in Knowledge Sharing, Montreal, Canada, pp. 1–10.
9. Uschold, M., King, M. (1995) Towards a methodology for building ontologies. Proceedings of International Joint Conference of Artificial Intelligence Workshop on Basic Ontological Issues in Knowledge Sharing, Montreal, Canada.
10. Lopez, M.F., Gomez-Perez, A., Sierra, J.P., Sierra, A.P. (1999) Building a chemical ontology using methontology and the ontology design environment. IEEE Intelligent Systems, 14(1):37–46.
11. Pinto, H.S., Martins, J.P. (2004) Ontologies: How can they be built? Knowledge and Information Systems, 6:441–464.
12. Noy, N.F., McGuinness, D.L. (2001) Ontology development 101: A guide to creating your first ontology. Knowledge Systems Laboratory Technical Report KSL-01-05, 1–5.
13. Ahmed, S., Kim, S., Wallace, K.M. (2007) A methodology for creating ontologies for engineering design. Journal of Computing and Information Science in Engineering, 7:132–140.
14. Sarder, M.B., Ferreira, S., Rogers, J. Liles, D.H. (2007) A methodology for design ontology modeling. Portland International

[1] http://bmir-protege-dev1.stanford.edu/webprotege

Center for Management of Engineering and Technology, Portland, Oregon, pp. 1011–1018.
15. Nanda, J., Simpson, T.W., Kumara, S.R.T., Shooter, S.B. (2006) A methodology for product family ontology development using formal concept analysis and web ontology language. Journal of Computing and Information Science in Engineering, 6:103–113.
16. Soininen, T., Tiihonen, J., Männistö, T., Sulonen, R. (1998) Towards a general ontology of configuration. AI EDAM, 12: 357–372.
17. Sim, S.K., Duffy, A.H.B. (2003) Towards an ontology of generic engineering design activities. Research in Engineering Design, 14:200–223.
18. Liang, V.-C., Paredis, C.J.J. (2004) A port ontology for conceptual design of systems. Journal of Computing and Information Science in Engineering, 4:206–217.
19. Kitamura, Y., Mizoguchi, R. (2003) Ontology-based description of functional design knowledge and its use in a functional way server. Expert Systems with Applications, 24:153–166.
20. Kitamura, Y., Washio, N., Koji, Y., Sasajima, M., Takafuji, S., Mizoguchi, R. (2006) An ontology-based annotation framework for representing the functionality of engineering devices. Proceedings of the ASME 2006 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (IDETC/CIE 2006), Paper DETC2006-99131, Philadelphia, Pennsylvania, USA.
21. Li, Z., Ramani, K. (2007) Ontology-based design information extraction and retrieval. AI EDAM, 21:137–154.
22. Catalano, C.E., Giannini, F., Monti, M., Ucelli, G. (2007) A framework for the automatic annotation of car aesthetics. AI EDAM, 21:73–90.
23. Grosse, I.R., Milton-Benoit, J.M., Wileden, J.C. (2005) Ontologies for supporting engineering analysis models. AI EDAM, 19:1–18.
24. Witherell, P., Krishnamurty, S., Grosse, I.R. (2007) Ontologies for supporting engineering design optimization. Journal of Computing and Information Science in Engineering, 7:141–150.
25. Lim, S.C.J., Liu, Y., Lee, W.B. (2009) Multi-facet product information search and retrieval using semantically annotated product family ontology. Information Processing & Management, 46(4):479–493.
26. Dartigues, C., Ghodous, P., Gruninger, M., Pallez, D., Sriram, R. (2007) CAD/CAPP integration using feature ontology. Concurrent Engineering, 15:237–249.
27. Oh, S.-C., Yee, S.-T. (2008) Manufacturing interoperability using a semantic mediation. The International Journal of Advanced Manufacturing Technology, 39:199–210.
28. Lin, H.K., Harding, J.A., Shahbaz, M. (2004) Manufacturing system engineering ontology for semantic interoperability across extended project teams. International Journal of Production Research, 42:5099–5118.
29. Cho, J., Han, S., Kim, H. (2006) Meta-ontology for automated information integration of parts libraries. Computer-Aided Design, 38:713–725.
30. Bellatreche, L., Dung, N.X., Pierra, G., Hondjack, D. (2006) Contribution of ontology-based data modeling to automatic integration of electronic catalogues within engineering databases. Computers in Industry, 57:711–724.
31. Zhao, W., Liu, J.K. (2008) OWL/SWRL representation methodology for EXPRESS-driven product information model: Part I. Implementation methodology. Computers in Industry, 59: 580–589.
32. Ye, Y., Yang, D., Jiang, Z., Tong, L. (2008) An ontology-based architecture for implementing semantic integration of supply chain management. International Journal of Computer Integrated Manufacturing, 21:1–18.
33. Ciocoiu, M., Nau, D.S., Grüninger, M. (2001) Ontologies for integrating engineering applications. Journal of Computing and Information Science in Engineering, 1:12–22.
34. McGuinness, D.L., Wright, J.R. (1998) Conceptual modelling for configuration: A description logic-based approach. AI EDAM, 12:333–344.
35. Felfernig, A., Friedrich, G., Jannach, D., Stumptner, M., Zanker, M. (2003) Configuration knowledge representations for Semantic Web applications. AI EDAM, 17:31–50.
36. Yang, D., Dong, M., Miao, R. (2008) Development of a product configuration system with an ontology-based approach. Computer-Aided Design, 40:863–878.
37. Lim, S.C.J., Liu, Y., Lee, W.B. (2009) Product analysis and variants derivation based on a semantically annotated product family ontology. Proceedings of the ASME International Design Engineering Technical Conferences & Computers And Information In Engineering Conference (IDETC/CIE 2009), Paper DETC2009-87160., (San Diego, California, USA), ASME.
38. Maedche, A., Volz, R. (2001) The ontology extraction and maintenance framework text-to-onto. Proceedings of the 2001 IEEE International Conference on Data Mining.
39. Navigli, R., Velardi, P. (2006) Learning domain ontologies from document warehouses and dedicated web sites. Computational Linguistics, 30(2):151–179.
40. Choi, N., Song, I.-Y., Han, H. (2006) A survey on ontology mapping. SIGMOD Record, 35:34–41.