Proceedings of the 11th International Conference on Manufacturing Research (ICMR2013), Cranfield University, UK, 19th – 20th September 2013, pp 107-112

TOWARDS AN ONTOLOGY-BASED PLATFORM-INDEPENDENT FRAMEWORK FOR DEVELOPING KBE SYSTEMS IN THE AEROSPACE INDUSTRY

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ABSTRACT

Aerospace engineering is considered to be one of the most complex and advanced branches of engineering. The use of knowledge based engineering (KBE) technologies has played a major role in automating routine design activities in view of supporting the cost-effective and timely development of a product. However, technologies employed within KBE systems are usually platform-specific. The nature of these platform-specific models has significantly limited knowledge abstraction and reusability in KBE systems. This research paper presents a novel approach that illustrates the use of platform-independent knowledge models for the development of KBE systems in the aerospace industry. The use of semantic technologies through the definition of generic-purposed ontologies has been employed to support the notion of independent knowledge models that strengthens knowledge reusability in KBE systems. This approach has been validated qualitatively through experts' opinion and its benefit realised in the abstraction, reusability and maintainability of KBE systems.

Keywords: ontology, platform-independent, software engineering.

1 INTRODUCTION

The design and manufacturing of aircrafts usually requires careful understanding and trade-offs between technological advancements, design constraints, best practice knowledge, management and cost. Therefore, there is a significant emphasis on capturing, structuring and reusing product and process knowledge in the aerospace industry in order to maintain a competitive advantage. The use of knowledge based engineering (KBE) methods and technologies has played a major role in automating routine and mundane design activities in view of supporting the cost-effective and timely development of a product. Stokes (2001) defined the term KBE as *'the use of advanced software technologies to capture and re-use product and process knowledge in an integrated way'.* Developing these KBE systems usually requires considerable effort in capturing, formalising and codifying knowledge.

KBE systems covers a wide range of activities within the product lifecycle such as geometry creation, computer aided design (CAD), computer aided engineering (CAE), computer aided manufacturing (CAM), computer aided production planning (CAPP) and in-service and maintenance support. The design and implementation of these multidisciplinary KBE systems are usually platform-specific and domain-dependent. Due to the nature of specificity within KBE systems, knowledge reusability becomes an issue because the 'design' and 'implementation' of KBE systems are tied down to a specific technological platform. In software engineering, a platform-independent knowledge model is a model of a business or software system that is independent of the specific technological platform used to implement it. The notion of a platform-independent model is often used in the context of a model-driven architecture approach. The idea is to use a transformation language to transform a platform-independent model into a platform-specific model. In software engineering, the advantages of platform-independent models is separation of business/functionality logic from implementation logic. However, this approach is often not employed in the design and development of KBE systems. For example, the design and development of a product component KBE system could be implemented in KF (Knowledge Fusion – automation language for KBE system) or in NX (Open API automation technology). Although these technologies possess powerful KBE functionalities that exploit advanced engineering knowledge, they are still considered as platform-specific models because its design and implementation logic is specific to a technological platform (i.e. specific programming language or operating system). Therefore, if there were to be a platform change, this will mean a complete re-write of the software system. This ad-hoc approach to developing KBE systems significantly limits abstraction and reusability as the engineering knowledge (i.e. key design parameters, design rules, mathematical expressions) within the KBE system is buried in code. The future generation of KBE systems will adopt a platform-independent approach so that the key design parameters and design rules for the KBE system is created independently of the KBE implementation as illustrated in Figure 1. Using a model transformation language will enable the transformation of platform-independent models into platform-specific models. This approach will significantly introduce a higher level of modularity and reusability in the design and development of KBE systems. Thus, reusing design and manufacturing knowledge from one KBE system to another becomes feasible.

In recent years, the engineering community (*i.e. researchers and industry experts)* has developed increased interest in the creation and maintenance of ontologies to support engineering activities. An ontology is a formal specification of a shared conceptualisation of domain of interest to a group of users. One of the most promising uses of ontologies as identified by Kitamura and Mizoguchi (2007) is that it enhances knowledge systematisation. This systematisation is mainly about the structure, abstraction and reusability of knowledge. Thus, this paper describes an approach that employs the use of ontologies as the basis of platform-independent knowledge models for designing and developing KBE systems in the aerospace sector.

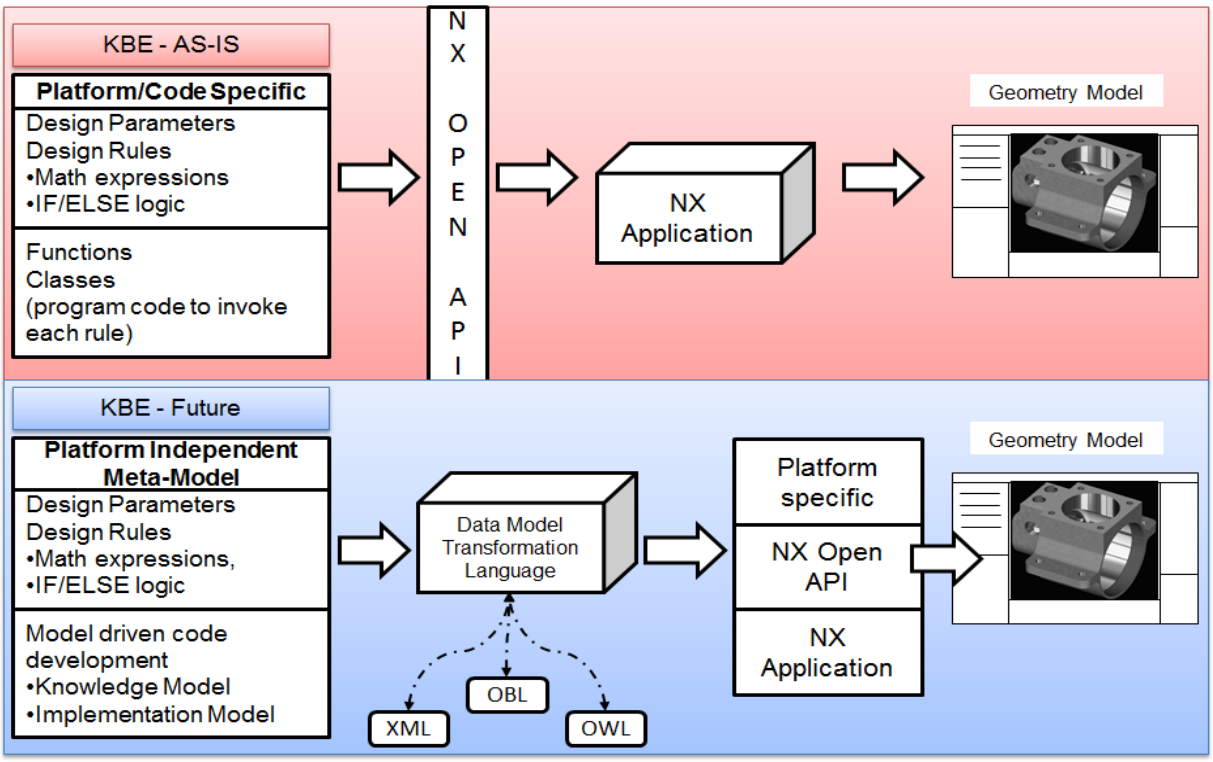

Figure 1: Platform Specific Model (PSM) vs. Platform Independent Model in the Aerospace Industry

2 RELATED WORK

Faigenbaum and McCorduck (1983) first established the definition of knowledge based engineering as an engineering discipline that involves the integration of knowledge into computer systems for the purpose of solving complex problems that normally require a high level of human expertise. Stokes (2001) identified that the utilisation of knowledge based engineering (KBE) systems is used to automate manual and time-consuming design activities and knowledge representation within KBE systems goes beyond representing geometrical data and other factors should be considered. It has been established within the literature that 80% of design engineers activities is related to repetitive, routine and mundane tasks, while the remaining 20% on innovative tasks (Skarka 2007). However, applying KBE systems could significantly reduce repetitive tasks and allow design engineers to gear their focus towards innovative design activities.

The application of ontology based approaches in conjunction with semantic technologies within product design activities has become an interesting area within the literature. Chang et al (2008) proposes an ontology based support for product conceptual design. Conceptual design is perhaps the most intricate and difficult activity in the product development lifecycle because knowledge at this phase is usually inaccurate and incomplete. Due to the large amount of heterogeneous information that exist in product design (e.g. component, manufacturing process, assembly, etc), an ontology based approach was utilized to enhance the flexibility and reasoning of distinct and diverse product design information based on inference mechanisms. It was concluded that this approach has extensive capabilities beyond the traditional database approach which restricts the maintenance and extensibility of information. Furthermore, the use of ontologies has been applied and deployed in the product design industry to represent functional design knowledge (Kitamura and Mizoguchi 2007). However, it has been suggested that majority of the developed ontologies in industry have been applied to broad businesses and do not possess the same level of granularity and detail that is usually required for mechanical design (Kyoung-Yun et al 2006).

Gunendran and Young (2009) propose a design realisation system bridging the gap between product design and manufacturing. A product model, manufacturing model and library model was developed as a result and the use of the OCL (Object Constraint Language) was used to construct the production rules for a power transmission shaft using the commercial K-Pacs E2KS ontology knowledge base. Chungoora and Young (2010) further illustrate the potential of adopting more expressive formalisms in ontology languages to ensure the integrity of product design and manufacturing knowledge models. It has been established that several families of ontology knowledge based representation exists. Formalisms representations such as, Frame-based languages (F-Logic) (Wang et al. 2006), Description Based Logic languages (Baader et al. 2007) and Common Logic which is an ISO standard (ISO/IEC 24707 2007) altogether forms different level of expressiveness for ontological representation for product design information. However, it has been identified that there is a need for mathematical intensive approaches for the product design domain (due to the definition of engineering geometry) within these logic languages to ensure that the true and precise meaning of concepts within an ontology is fully expressed in order to prevent semantic loss between different systems (Das et al 2007).

The literature has highlighted that although there have been attempts made to use ontologies for developing KBE systems, there is lack of research studies focused on developing frameworks that will support the notion of ontology-based platform-independent knowledge models in KBE systems. There is no clear formalised link between ontology development and KBE systems.

3 ADOPTED RESEARCH METHODOLOGY

Due to the collaborative nature of the research study, it was essential that a research methodology satisfying both academia and industry was selected. A qualitative research approach and action research methodology has been adopted in order to jointly develop the framework with design and manufacturing engineers with several years of KBE industrial experience. The research commenced with a familiarisation stage in order to understand the KBE system domain within the aerospace industry. A total of 12 interviews were conducted with KBE experts. Participants included integrated design and manufacture engineers, knowledge based engineers, technical KBE leads with several years of aerospace industrial experience ranging from 10 – 25 years. Interviews commenced with other software engineering experts in the aerospace domain. It was established that the notion of a platform independent knowledge model is often employed in the software engineering discipline. However, this notion in KBE systems is not clear and there was a need to investigate this area and quantify its benefits. The interviews also clarified that some of the key KBE challenges faced in the aerospace sector is the challenge of reusing KBE knowledge from one KBE system to the other due to the domain-specific and platform-specific approach often employed within KBE systems. A case study was conducted within the aerospace industry following the developed framework to develop an ontology-based KBE system for primitive geometric shapes as a proof of concept demonstrator.

4 DEVELOPMENT OF AN ONTOLOGY-BASED PLATFORM-INDEPENDENT FRAMEWORK FOR IMPLEMENTING KBE SYSTEMS

A framework for developing platform independent models using an ontology as the basis has been developed in the aerospace industry. The framework consists of four-phase as illustrated in Figure 2, namely (1) Capture KBE system knowledge (2) Ontology Model Construct of KBE system (3) Platform Independent Model (PIM) Technology Selection and Implementation (4) Integration of PIM KBE knowledge with CAD system. This framework forms a set of guidelines for KBE experts to employ in order to move from platform-specific KBE approach to platform-independent KBE approach. The first phase is to capture the knowledge required for the KBE system. This includes clearly identifying the purpose of the KBE system, defining 'use case' scenarios and functional and non-functional KBE system functionalities. A knowledge capture template sheet is recommended in order to capture specific knowledge required for the KBE system. The outcome of this phase should be a clear identification of the key design parameters and key design rules required for the KBE system. The second phase tackles the formalisation of the captured knowledge into an ontology for the KBE system. It is essential to identify a list of KBE concepts, KBE attributes and define concept to concept relationships as well as concept to attributes relationships. There is also a need to identify specific instances of the concepts identified. It is recommended to employ an object oriented paradigm (OOP) approach and model driven architecture (MDA) approach for this phase. It is also essential to graphically visualise and represent the ontology meta-model of the KBE system. One of the most important aspect of a KBE system is the rule-base. Therefore, there is a need to develop rules that are more maintainable and adaptable. A rule-based approach that provides such features are known as 'declarative rules' rather than the commonly used 'procedural rules'. In declarative programming, the rules are specified by defining what the program should accomplish rather than describing how to go about accomplishing it. Therefore, the logic of the computation is expressed without describing its control flow. The declarative approach to defining KBE rules are more adaptable and maintainable than the procedural approach and this can replace hard to maintain nested IF… THEN.. ELSE coding commonly adopted in KBE systems. The outcome of phase two is a formalised-ontology, clearly representing the KBE design parameters, rule-base (as a set of declarative rules) as ontology concepts and attributes.

The third phase of the framework focuses on selecting a 'fit for purpose' platform independent technology. Though, there are not many platform independent technologies that support KBE systems. However, there are capable ontology-based technologies that can be used for this purpose. It is essential to select a technology that supports declarative programming in order to model the KBE design rules using this approach. The KBE ontology model developed in the previous phases is implemented using the appropriate ontology-based technology. There might be a need to employ two ontology-based technologies in this phase. The first for modelling the KBE domain knowledge (i.e. design parameters as a set of concepts and attributes) and the other for modelling key design rules for the KBE system.

The fourth phase is to select an API for the CAD system. A suitable API will allow the integration of the platform-independent ontology knowledge-base with the KBE CAD system. The input and output of the ontology-knowledge based model is integrated with the KBE CAD system using a suitable API. It is important to note that the last phase might be time-consuming due to the need to understand the API. Platform independent ontology-based models might require more time to implement than the conventional platform-specific approach. However, the benefit of these platform independent models is realised in knowledge abstraction and reusability. This is of course essential for the long-term and future of KBE systems and for maintaining and preserving KBE knowledge. Important keywords used in the framework are described below: API – Application programming Interface, MDA – Model driven architecture and OOP – Object oriented paradigm.

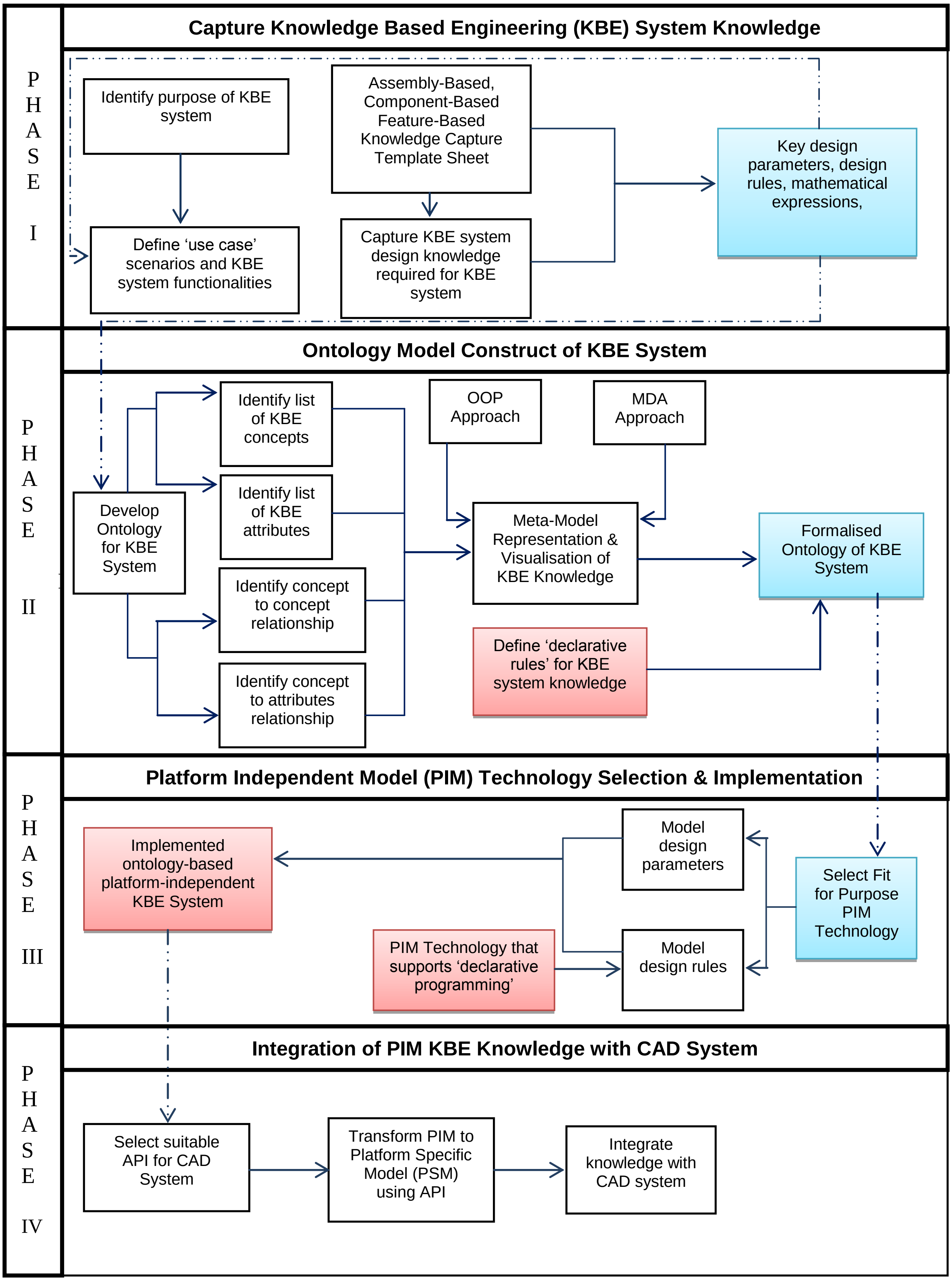

Figure 2: A framework for developing an ontology-based platform independent model for multidisciplinary KBE Systems

5 VALIDATION

The ontology-based, platform-independent model approach for developing KBE systems in the aerospace sector has been validated through experts opinion in a series of sessions. The experts agreed that the approach will significantly increase knowledge reusability and abstraction. However, due to the fact that there are not many technologies that supports this notion within KBE systems, it might be difficult to exploit full engineering knowledge and there might be limitations to the functionalities and capabilities of the use of available technologies for developing KBE systems. A case study was also conducted in the aerospace sector following the phases of the framework and showcasing a proof of concept demonstrator implementing an ontology based platform-independent model for primitive geometrical shapes in product design and development. It was identified that this approach should be employed in the future generation of KBE systems due to its benefits which are mainly high-level of reuse, reduction in development efforts and better management of KBE development complexity.

6 CONCLUSIONS

This research paper has introduced the need to employ ontology-based, platform independent models in the design and development of KBE systems. A novel approach has been defined that aims to bridge the link between ontologies, platform independent technologies, and KBE product design systems. Evidently, there is a benefit in employing this approach for the long-term development and maintenance of KBE systems. This approach has been validated through experts' opinion and case studies. However, there is a need to apply this approach on a larger scale (i.e. complex geometry components) to validate its scalability. There is also a need to raise the technology readiness level of the use of ontologies in the development of KBE systems as most of the application of this approach has been in demonstrator prototype. However, the framework developed will serve to support the notion of an ontology-based, platform-independent models for KBE systems.

ACKNOWLEDGEMENT

The authors would like to thank EPSRC and the industrial partner for sponsoring this research project.

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