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TOWARDS THE SEMANTIC INTEROPERABILITY BETWEEN KBE AND PLM SYSTEMS

Pablo Bermell-Garcia[1], Ip-Shing Fan[2], Adrian Murton[3]
[1]Unilever R&D, Port Sunlight
[2]Cranfield University
[3]Airbus UK

ABSTRACT
As the Product Lifecycle Management (PLM) concept for distributed product development consolidates in engineering design practice, its role as a tool for systematic Knowledge Management (KM) is widely discussed across the research community. An ongoing standardisation effort at the Object Management Group (OMG) has identified the interoperability between Knowledge Based Engineering (KBE) systems and PLM as a contributing instrument. Managing the knowledge retained using KBE technology is only a partial solution for the management of the intellectual capital delivering complex product/service systems. However, the KBE/PLM interoperability has attracted industrial interest as a strategy to capitalise the efforts made in KBE and to coordinate its deployment across engineering programmes. The work to create the standard follows a procedure in which its requirements have to be prepared and approved by the OMG. When established, the 'KBE Services for PLM' standard shall be used by the global computing industry to create interoperable software so that engineering knowledge encoded in one CAD/KBE software could be interchanged with other CAD/KBE software, and managed in a PLM environment so that the knowledge could be retrieved and updated during the lifecycle of the product. This paper is intended to report to the Engineering Design community represented in ICED07 on the research leading to the current set of requirements for such standard.

Keywords: Knowledge Based Engineering, Product Lifecycle Management, Information modelling, Engineering Knowledge Management.

1 INTRODUCTION
Rapid and cost -effective methods for the design of engineering products can provide significant competitive advantage to manufacturing industries. The effective use of knowledge for avoiding repetitive work has demonstrated significant savings in a variety of engineering programs. In the 1980s the integration of Artificial Intelligence (AI) techniques in CAD tools drives the appearance of KBE systems. The first commercial success of the technology is the *ICAD* System. The software uses a LISP-based language closely integrated with a geometric modeller so engineers can encode engineering knowledge and run data generation programs. In the early 1990s use of KBE technology was primarily by aerospace and automotive companies. In the late 90s CAE vendors at the high end of the market (i.e. *Dassault Systemes* and *Unigraphics*) started to include KBE functionalities in their CAD suites [1]. The acquisition of *ICAD's* owner company by *Dassault Systems* is not an isolate case, considering that *Autodesk*, another CAD systems vendor has acquired the company responsible for the *Intent!* KBE product [2, 3]. Similarly, the *Unigraphics* KBE functionalities are underpinned by the *Knowledge Fusion* product come from a past partnership in which *Intent!* technology was transferred to the system [4]. Alongside these commercial strategies from CAD vendors, it has been reported by [5] that medium size engineering firms are increasingly taking up on KBE technology. In essence, KBE enables the semantic enrichment of Computer Aided Design (CAD) models so explicit engineering knowledge can be embedded. More importantly, KBE technology supports knowledge management by enabling the systematic retention of engineering problem solving procedures [6].
It is a challenge to manage this knowledge throughout the lifecycle of a product. The utility of KBE technology has been recognised by the progressive integration of its functionalities in Product

Lifecycle Management (PLM) support tools. In this context, a PLM system packages a set of software functionalities that support the execution, the storage of data and the coordination of engineering projects. However, KBE applications face interoperability issues that may restrict the potential for the effective use and deployment of the technology by end users and vendors alike. An effort to deliver a standard information model facilitating this interoperability has been recently launched within the Object Management Group (OMG). This paper describes the research leading to the requirements for the "KBE services for PLM" standard.

Standardisation of KBE software services reduces the risk of knowledge exchange problems across multiple systems. At the same time, it opens the possibility of using KBE as a core technology for the reuse, sharing and maintenance of engineering knowledge across the PLM spectrum of applications.

2 ENGINEERING KNOWLEDGE MANAGEMENT THROUGH KBE

It is widely recognised that Knowledge Management (KM) is a key practice for 21st century organisations attempting to capitalise on their expertise and know-how. Various researchers acknowledge the current debate on the role of computing technology in KM [7, 8]. The inseparability of KM from computer-based support has been discussed in [9]. The study recognises the importance of information and communication technologies (ICTs) in speeding up knowledge intensive activities carried out by individuals, groups and systems. In engineering domains, a distinction between ICT focused in personalisation and codification KM has been pointed out by McMahon, [1]. Personalisation refers to computer tools supporting the management of human resources and communication. Codification is regarded as the use of ICTs for collecting and organising knowledge. According to this classification, examples of codification tools for KM are KBE systems and ontology editors. On the other hand, computer supported collaborative work tools (CSCW) and web-based communities of practice are typical personalisation tools for KM.

2.1 Codification and personalisation aspects of KBE

KBE toolsets allow the encoding of engineering data generation processes using specialised languages to explicitly declare the instantiation of software objects on CAD systems. Using their generative modelling capabilities, engineers predefine the process to create of a wide range of engineering data elements (geometry, bills of material, etc.). Integrated modelling is supported by the explicit definition of engineering rules to control the instantiation of the data. Engineering rules can be used to enrich KBE models from multiple engineering viewpoints such as manufacturing, ergonomics, and many others.

KBE is usually presented as a codification KM instrument [10-13]. In fact, KBE software tools "out of the box" are just codification KM instruments. However, much of the value of the technology as a KM strategy is in its impact on engineering practice as a personalisation KM instrument. Gaining the benefits of KBE as a personalisation instrument requires methodological support and organisational endorsement rather than just tool implementation. The implementation of KBE encourages the following beneficial KM practices:

- **Reflective analysis of engineering activities**. KBE projects usually start with the identification of a routine or variant engineering task suitable to be automated. Identifying a business case for KBE is in itself a continuous improvement engineering practice. Furthermore, deploying KBE has other beneficial side effects like standardising terminologies, clarifying procedures and identifying engineering decisions.
- **Identification of multidisciplinary knowledge areas necessary to solve engineering problems**. KBE implementations usually integrate engineering rules from different knowledge domains. Their elicitation enforces an interdisciplinary exchange of information, knowledge sharing and establishment of collaboration networks.
- **Documentation of engineering best practices**. Either by using formal KBE codes or more informal descriptions, the knowledge about engineering procedures is explicitly retained in a way that otherwise would remain tacit.
- **Making more efficient the work that is not fully supported by software systems**. Software development usually involves high costs associated not only to coding activities but to knowledge capture and requirement definition. KBE gives a cost-effective computational solution for engineering jobs in which automation is needed and software development is expensive.

A unique approach to realise both the codification and personalisation KM capabilities of KBE is the Methodology and Tools for Knowledge Based Engineering (MOKA) [14]. Using MOKA, major aerospace and automotive companies have deployed KBE as an enterprise best practice rather than just as a solution for automating certain engineering tasks. In addition to KBE codification tools, MOKA´s methodological support includes procedures to interview experts, ontological schemas to organise the knowledge and tools for representing and publishing the knowledge across the organisation.

Despite of this, MOKA make little commitments to the management of knowledge by using the capabilities of PDM or PLM environments. Observations from industrial MOKA implementations have revealed the use of extensions to the methodology to support the management of changes in knowledge repositories. This drives the hypothesis that many of those knowledge management operations could be carried out under the PLM scope of applications.

3 TOWARDS INTEGRATED KBE IN PLM

This research advocates the interoperability between KBE and PLM systems. The use of KBE as a codification instrument can be complemented by PLM as the personalisation instrument in KM practice. This approach shall provide an ICT mediated mechanism to share, reuse and maintain KBE applications as resources in networked enterprises. Achieving the functional interoperability between both technologies brings the opportunity to provide “out of the box” KM solutions. Consequently, investments to achieve KM technology and culture in small organisations shall be reduced. The users’ awareness of both technologies shall facilitate KM practice by leveraging well known tools rather than by introducing disruptive systems and frameworks.

The integration of KBE within product lifecycle systems is early discussed as a need for future engineering support tools by Penoyer et al. [15]. The research from Subrahmanian et al. suggests that a possible path to realise the PLM concept as a strategy for knowledge capitalisation consists in the integration of existing standards related to PLM [16]. This includes not only product engineering data schemas but also other standards for information modelling and formal knowledge representation.

Similarly, a KBE/PLM integration roadmap has been suggested by Prostep-iViP association on a study on product engineering strategic areas subject of attention up to the year 2010 [17]. The report recognises that at the moment KBE functionalities being progressively integrated with mainstream CAD solutions. Considering this as an early stage in its evolution, KBE technology shall become fully integrated with PLM by 2010. Table 1 show the milestones identified in the KBE/PLM convergence roadmap.

Table 1. Milestones for a KBE technology roadmap (source: [17]).

Timeline	***Targets to be achieved***
By 2007	Implementation of KBE applications with the support of CAE systems.
By 2008	Knowledge integration among CAE tools and management systems in PLM environments. Standardisation of the knowledge representation with the use of standards in information modelling (STEP, UML, XML, etc.).
By 2009	Implementation of a framework for integrated product development in a KBE environment.
By 2010	Integration of the KBE framework with a PLM environment.

The bottom line of these initiatives is that semantic modelling will play a significant role. A semantic model describes the concepts relevant in a particular situation with a high level of precision. Intensive research from various computer science areas has made available generic upper level information models capable of representing domain knowledge. Their robustness and scalability has transformed a number of these approaches from research initiatives into internationally supported standards for information modelling. Examples of standardised modelling frameworks are the Semantic Web for e-business and web based systems supported by the W3 Consortium [18], and the Model Driven Architecture (MDA) for interoperability between IT systems, owned by the Object Management Group (OMG) [19].

This research pays special attention to the OMG’s MDA as a current industry-supported technology to embrace the more generic concept of Model Driven Engineering (MDE). According to Schmidt, MDE

is the result of various research efforts to address the current platform complexity in software development [20]. The MDE approach combines the definition of domain specific modelling languages together with data transformation engines and code generators. The connections between MDE and the KBE and PLM interoperability can be appreciated when considering KBE languages as domain-specific modelling languages for CAD data generation and the possibility of using metadata transformations and mappings to interchange information between KBE and PLM systems.
The OMG has been playing a proactive role in establishing standards to achieve software interoperability in a variety of strategic application domains. Domain Task Forces (DTFs) cover areas in Business Modelling & Integration, C4I, Finance, Government, Healthcare, Life Sciences Research, Manufacturing Technology & Industrial Systems (MANTIS), Robotics, Software-Based Communications and Space. DTFs are composed by representatives from industry, academia and government agencies. OMG membership costs are transformed into business advantages by influencing and having privileged access to emerging software standards and technologies. In 2004, the MANTIS Task Force identified that KBE is maturing to become a significant software application for the manufacturing industry [21]. The interests of MANTIS in KBE stems from the prediction of the kind of software applications needed to support product/service systems in the knowledge economy, and the associated interoperability issues.

3 RESEARCH METHODOLOGY

In typical interoperability standardisation efforts, a common model is agreed by major users and vendors to allow vendor solutions to exchange information with the agreed protocol. In the context of this research the following objectives are defined:

(a) To understand major industrial use cases regarding the interoperability of KBE systems
(b) To elicit a set of requirements for a KBE/PLM interoperability standard

The outcome of this research is a Request for Proposal (RFP) for the "KBE Services for PLM" standard. This is a major milestone in standardisation processes within the OMG. A RFP document defines the set of requirements that a standard for IT systems interoperability has to meet.
The research leading to the scoping and agreement of the interoperability needs to be expressed in the RFP is carried out through the compilation of the needs from KBE technology users and vendors. The researchers are involved in the process as facilitators in the discussions and are also responsible to collect and unify the different views of the participants. Resulting from these activities, the authors have edited the RFP issued by the OMG. This work is carried out by following the cyclic process illustrated in Figure 1.

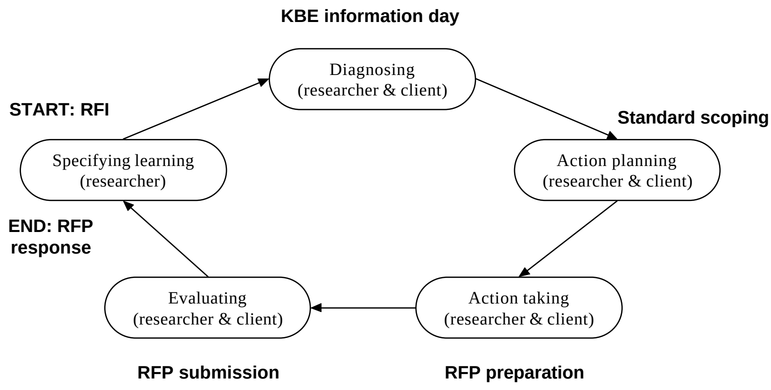


Figure 1.Research methodology.

Before the research start, a Request For Information (RFI) document was issued by the OMG to identify use cases and expectations regarding the standardisation of KBE software services [22]. The two responses to the RFI predicted potential benefits from the interoperability between KBE systems and the exchange of information between them and digital knowledge repositories [23, 24].
A KBE information day was hosted by the OMG in 2004. More than 30 attendants and 11 representatives from the community of engineering software users, vendors and researchers presented their views on standardising KBE technology. Starting from this event a standardisation effort for

KBE software systems was launched. Data had been collected in the research through structured focus meetings involving several players from the community of KBE and PLM users and vendors. Other interaction activities involved off-line interviews with industrial KBE and PLM practitioners. Table 2 gives information on the participants whose views have been collected and unified in the RFP.

Table 2.Detailed research design

Participants	***Data collection***	***Research Outcomes***
Aerospace (6) Automotive (1) Software vendors (4) Government agencies (2) Academia (2)	KBE info day 11 presentations focused on KBE standardisation collected	**Diagnosis** Opportunities to launch a KBE services standardisation effort identified
	2 OMG technical meetings	**Action planning** Scope of the standard adjusted to "KBE services for PLM"
	3 Off-line interviews with KBE/PLM practitioners	**Action taking** Edition of the RFP document
	1 OMG technical meeting	**Evaluating** "KBE services for PLM" RFP approved by the OMG's Architecture Board. Two letters of intent received
	1 OMG technical meeting	**Specifying learning** Initial submission received and diagnosis for further refinements

During the standard scoping stage, the connection with other on-going OMG standardisation efforts including Product Lifecycle Engineering (PLM), Business Rules, etc becomes apparent. The scope of the standard was re-defined as an international standard for 'Knowledge Based Engineering (KBE) services in a Product Lifecycle Management (PLM) environment'.

When certain level of maturity of the scope and purpose of the standard was reached, the RFP document was edited by the researchers and submitted to the OMG. The RFP had gone through the rigorous OMG's Architecture Board (AB) approval process and it had been published in September 2005 [25]. The AB review process ensured the consistency of the standard requirements with the MDA technical approach for software standardisation and interoperability.

The industrial value of the research leading to the RFP has been implicitly validated by the participation of major KBE and PLM users, vendors and leading researchers in the area. Evidence of this can be seen in the intention to respond the RFP that two OMG members have formally expressed. A new research cycle has been started.

4 KBE SERVICES FOR PLM

The RFP document solicits an abstract syntax that can be used to describe KBE software services. This common interoperability model can be used to exchange information between KBE systems. From a wider perspective, the model can be used to manage the knowledge contained in KBE applications by taking the advantage of existing functionalities built in PLM data repositories. Additional information given in the RFP includes background information, scope and issues to be considered.

4.1 KBE systems interoperability

The need to support the interoperability between KBE systems becomes evident when the data generation process and the knowledge encoded into a KBE application from a system *A* has to be transferred into a system *B* (Figure 2).

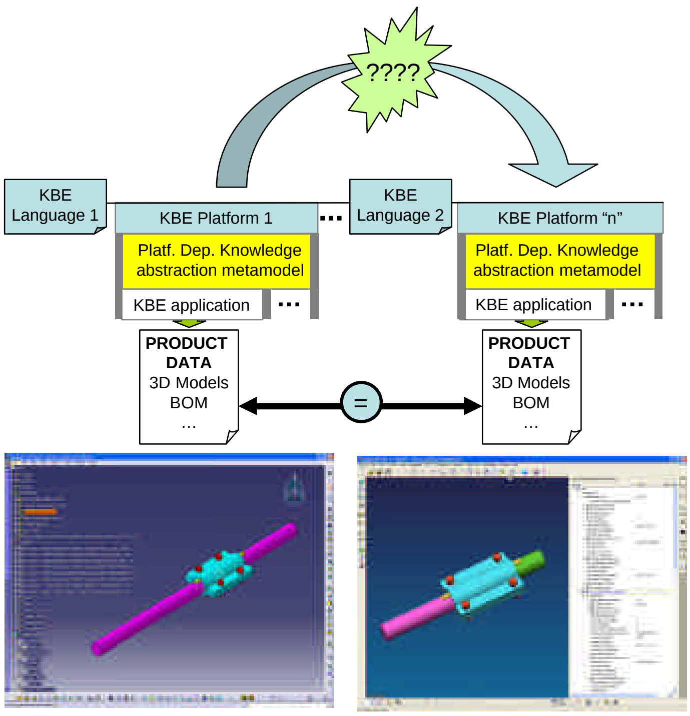
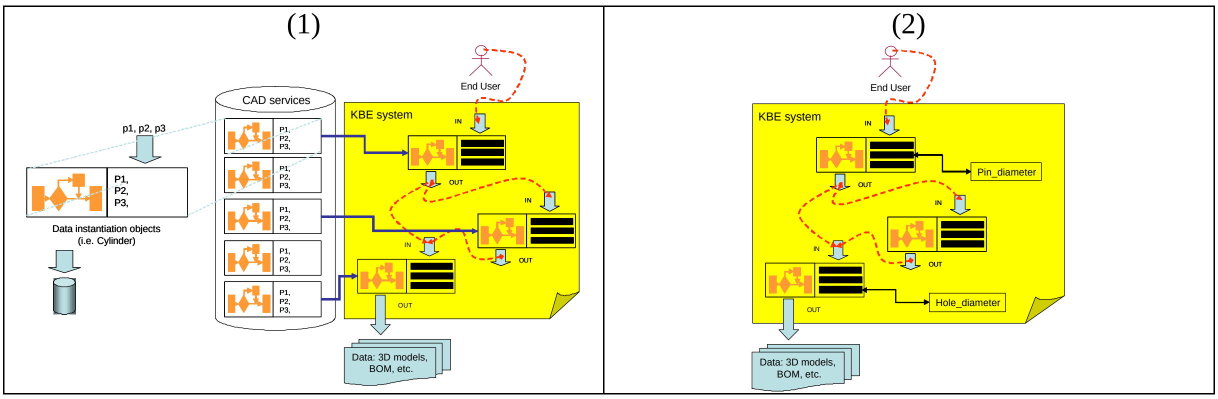


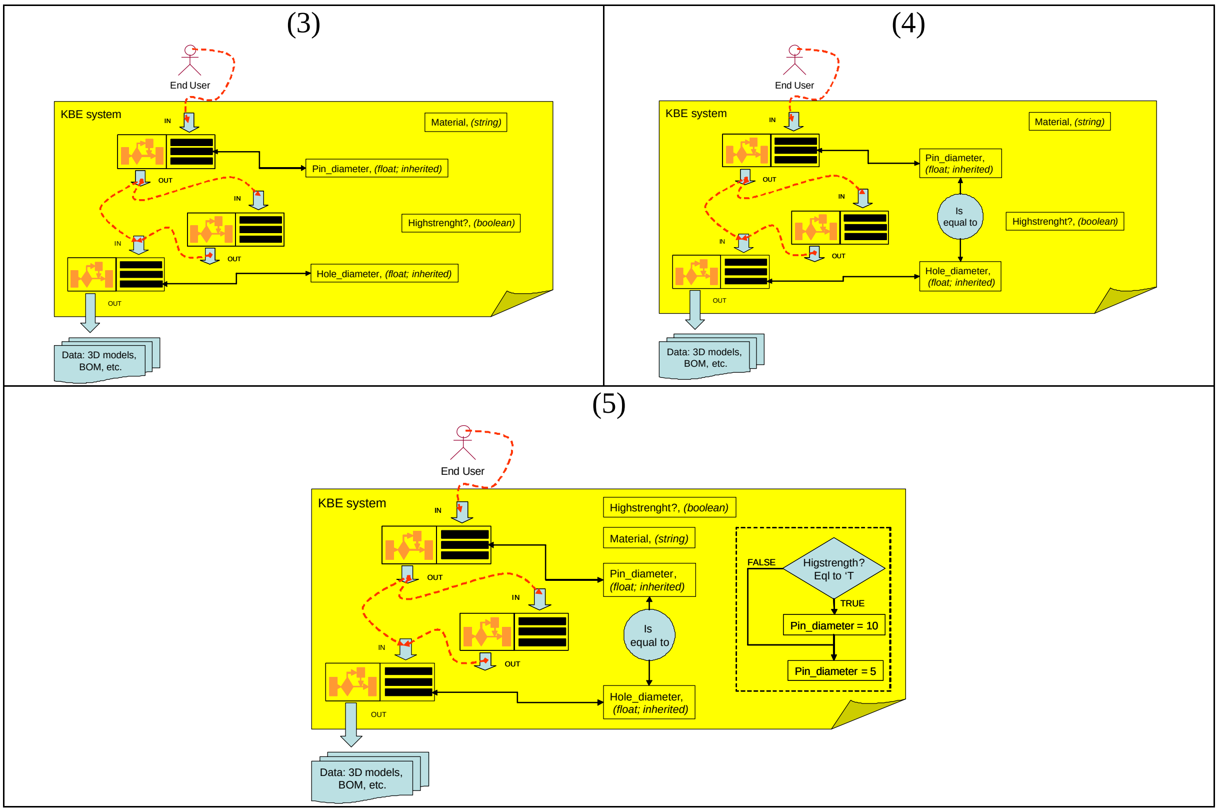
Figure 2.KBE interoperability challenge.

KBE-enabled modelling tools use a domain-specific language particularly expressive for the specification of data generation processes using a CAD engine. The set of operations that a KBE system is capable to represent include the definition of engineering rules, domain-specific parameters and other constructs. While this represents an abstract syntax for describing KBE functionalities with certain level of commonality across systems, a concrete syntax is tied to the specific KBE language available in the particular vendor solutions. The research identifies a set of five basic KBE operations for which an abstract syntax can be defined to act as a high-level language for expressing KBE functionalities (Table 3):

1. The assembly of CAD data instantiation objects to model the target engineering problem solving task as well as the clarification of how these software artefacts interact.
2. The assignation of domain-specific terminologies to the internal attributes of the assembled CAD data instantiation objects.
3. The creation of data attributes with special significance in the domain-specific problem to be addressed by the KBE application.
4. The definition of relationships between the attributes explicitly declared in the application.
5. The definition of engineering rules capturing engineering decisions.

Table 3. KBE operations.





4.2 KBE and PLM systems interoperability

During the research, specific concerns have emerged on the role of the KBE and PLM interoperability. PLM technology as an enterprise-wide repository for engineering data shall facilitate the management of the knowledge stored in KBE systems. Secondly, PLM as key infrastructure for engineering team coordination shall be used to manage the KBE deployment processes within organisations. An opportunity for responding to these concerns is the description of executable KBE models as "items" to be managed in a PLM environment. The concept of item in PLM is commonly referred as an undifferentiated managed object that has generic metadata such as owner, identifier, creation date and others [26]. In the context of this research, the notion of item is attached to that of "KBE resource" as a reusable piece of KBE functionality systematically stored in PLM data repositories.

This aspect is explicitly stated in the section 6.1.6 of the RFP document. The rationale behind this way of supporting the KBE/PLM interoperability results from transferring the specific concerns into a strategy for KBE deployment in distributed computing environments. On this basis, two business functionalities shall be supported by standardised "KBE services in PLM":

- Building the capability to store KBE resources within PLM repositories so they can be indexed and retrieved for reuse across engineering programmes.
- Building the capability for a PLM-mediated coordination for the different stages of KBE resources lifecycle in engineering organisations.

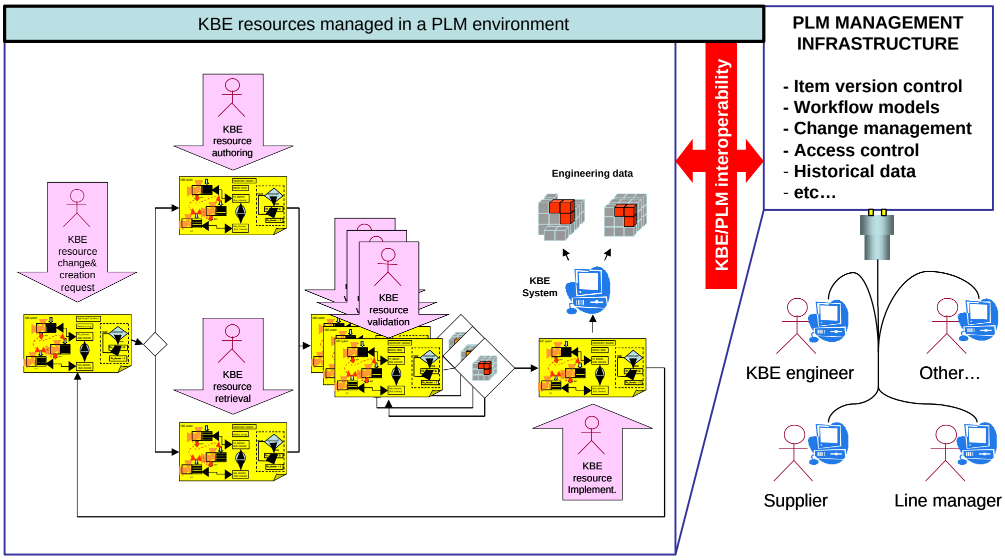


Figure 3. KBE/PLM interoperability.

4.3 Semantic modelling for the standard development

The end result of the "KBE services for PLM" standard is an information model describing a domain specific modelling language to respond to the use cases described above. The focus of the modelling activities realising the standard is decomposed into two interconnected areas of coverage having the following objectives:

- To identify and specify a metamodel of functional services that allows current KBE technology to standardise and share the information that generates engineering data.
- To specify the necessary metamodel of services or extensions to current standards so as to enable KBE services to be integrated into PLM systems and consequently benefit from the information management infrastructure available in PLM systems.

The resulting metamodel shall define the concepts in the KBE/PLM interoperability domain, the relationships among those concepts as well as the constraints associated with them. The OMG's MDA framework is to be used as the overall approach for the standard development. At the heart of MDA, the Meta Object Facility (MOF) is the upper level modelling language from which domain-specific modelling languages are derived. The "KBE services for PLM" data model is an instance of the MOF language but at the same time describes an abstract syntax for KBE software services in PLM that is not tied to any specific platform (Figure 4).

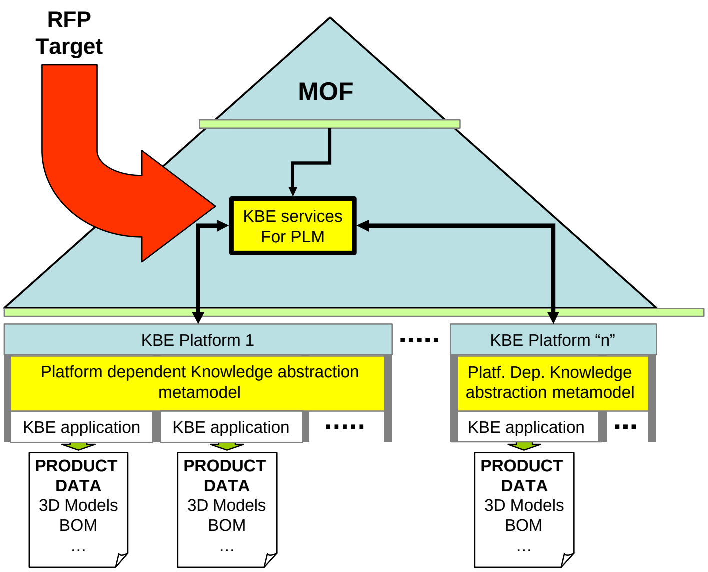


Figure 4. Positioning of the standard.

According to the MDA terminology the “KBE services for PLM” metamodel is a Platform Independent Model (PIM). Once the PIM is defined, the MDA approach allows the definition of mapping rules to a particular concrete syntax tied not only to programming languages but also to metadata schemas. These mappings are known in MDA as the Platform Specific Model, (PSM). The standard development pays special attention to the OMG’s XML Metadata Interchange standard [27], a MDA technology enabling the mapping of PIMs into XML Document Type Definitions (DTD) or XML Schemas with the aim of exchanging knowledge between KBE and PLM systems.

5 DISCUSSION

The research reported here is used as the basis for developing a robust interoperability data model for KBE and PLM systems. The selected technical framework to realise the model is the OMG’s MDA. Another standard alternative for advanced formal semantic modelling is the W3C’s Semantic Web Services (SWS) approach. In the SWS framework, the Web Ontology Language (OWL) would be the basis to define a domain model for KBE services. The MDA and the SWS seem to be associated to the Software Engineering and the Knowledge Engineering practice respectively. However, functional overlaps between both approaches increase as web-based and object-oriented systems become more integrated. In this direction, the Ontology Definition Metamodel is a common effort between these two communities to reduce the gap between domain knowledge modelling in software development practice [28].

An important advantage of aligning the standard development with OMG based technologies is the opportunity for continuous evaluation and improvement through a dedicated community of industrial IT practitioners in the MANTIS group. The team assessing the “KBE services for PLM” development has representatives from independent players involved in the development of engineering IT systems including Government Agencies and academic institutions.

On the other hand, continuous feedback from engineering practitioners outside the OMG is ensured through the direct contributions to the research from representatives of the KBE division in a large aerospace manufacturing organisation. Such team is recognised as one of the leading KBE technology innovators at the industrial level. Its involvement in the research has also facilitated the collection of feedback from other influential players such as major engineering software vendors and consultancy firms by disseminating the standardisation activity across the KBE community.

At the moment a set of open questions having direct implications on the contents of the standard have been included in the RFP:

1. How KBE services interact with the range of different engineering data generation facilities beyond geometry generation. This includes existing modules in CAD/PLM such as mechanical analysis or computer aided manufacturing?
2. How the proposed metamodel is used to exchange information that allows the transfer of data from one KBE/PLM system to another?
3. How to reuse and extend existing OMG standards?
4. How data models contained in standards developed by ISO TC184/SC4 can facilitate the fulfilment of the basic KBE services functionalities, i.e., what are the data meta-classes in STEP and how can they be made available in the resulting KBE services for PLM metamodel?
5. How proposals provide means to protect the intellectual property embedded in engineering rules?

6 CONCLUSIONS

This paper presents the initial outcomes from the research leading to an international standard for the semantic interoperability between KBE and PLM systems. The resulting RFP document gives a unified view of the scope for such standard. When established, the ‘KBE Services for PLM’ standard shall be used by the global computing industry to create interoperable software so that engineering knowledge encoded in one CAD/KBE software could be interchanged with other CAD/KBE software, and managed in a PLM environment so that the knowledge could be retrieved and updated during the lifecycle of the product.

The publication of the RFP by the OMG’s AB evidences the consistency of the technical approach to be used in the standardisation process. There are commitments to the submission responding the RFP have been expressed by two OMG member organisations. The first of them is a highly specialised software vendor offering leading edge CAD-based searching technology for the retrieval of engineering data. The second is a major engineering consultancy firm that develops KBE and PLM solutions for a range of industrial sectors including aerospace and automotive. In addition, an initial submission responding to the RFP has been made available.

6.1 Further work

An initial response to the "KBE services for PLM" was submitted to the MANTIS Task Force in June 2006. The submission contents include a data model for representing engineering knowledge based on the Core Product Model (CPM) and the Open Assembly Model (OAM), [16]. In the submission's review meeting, common agreement was reached on the need to establish connections from the metamodel describing "KBE services for PLM" and existing engineering knowledge representation schemas.

Further research in the standard development shall consolidate key published models through a comparative survey on design knowledge modelling languages. Apart from the CPM and the OAM, the MOKA Modelling Language (MML) [14] and the SysML language [29], are initial candidates. Another approach to be explored is the use of process-based modelling languages to describe the procedural nature of the KBE services operations. An ongoing OMG activity Business Process Definition Metamodel (BPDM) has points of connection with "KBE services for PLM" [30]. Similarly, within the ISO STEP community the concept of procedural shape models is gaining momentum [31, 32]. Existing data models within STEP supporting the concept need to be investigated.

In addition to the use of metamodels to represent engineering knowledge, further modelling entities shall be included in the standard to support the management of the knowledge on a PLM environment. The initial basis for defining this set of entities is the "PLM services" standard [33]. This OMG specification specifies a MOF-complaint PIM describing basic PLM software services for collaborative engineering such as browsing product structures and change management.

A set of criteria shall be developed to assess the collected models with respect to their value for: (a) supporting the management of engineering knowledge through PLM; (b) being possible to be modelled using the MDA approach. A Wiki is expected to be created to allow other researchers to participate in the nomination and selection of the key research work.

The engineering and design research community has a major role to play in the development of this international standard. While the business scenario and engineering knowledge practice is yet to be fully mature, a wealth of research has studied different aspects of this development. Development of the product/service concepts has been reported by [16, 34]. The approaches to model, represent and use knowledge in engineering spans the work of AI in design to KBE work represented by authors [6, 14, 35, 36]. The nature of work of an engineer has been studied by Crabtree [37], Hales [38], and Eckert [39]. The latter line of research makes explicit the social and work context that should lead to the design of ICT systems more easily adapted into an engineering business. While research advances on a broad front of, these results are a collection of small developments. An integrating effort has been missing to bring established engineering research into a body of knowledge that can influence industrial development at a strategy level. The EPSRC Grand Challenge project in 'through-life information and knowledge management for product-service systems' led by the University of Bath is a major UK effort that could deliver the impact to industry [40].

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Contact: Pablo Bermell-García
Unilever R&D, Port Sunlight,
Packaging Design Technology Centre
Wirral, CH63 3JW
Tel: +441516413553
Email: Pablo.Bermell-Garcia@unilever.com