INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED11
15 - 18 AUGUST 2011, TECHNICAL UNIVERSITY OF DENMARK

CHALLENGES IN SEMANTIC KNOWLEDGE MANAGEMENT FOR AEROSPACE DESIGN ENGINEERING

Isaac Sanya[1], Essam Shehab[1] and Dave Lowe[2]
(1) Cranfield University, UK (2) Rolls-Royce Plc, UK

ABSTRACT
The efficient and effective management of knowledge is becoming increasingly important within the aerospace design engineering sector due to the complexity of product development. The ongoing collaboration of multidisciplinary specialist skills is of necessity for the development of advanced and complex products throughout the aerospace sector. This paper presents various challenges that could hinder the management of knowledge within the aerospace design engineering environment. Furthermore, this paper demonstrates that ontological engineering for semantic knowledge management has been proven to be an effective means of structuring and organising complex knowledge. However, various challenges such as the ambiguity of vocabulary, no shared agreement of meaning between design and manufacturing engineers, no formal notation for representing ontologies and engineers not willing to utilise ontological tools for structuring knowledge are detrimental issues hindering the effective management of knowledge within aerospace design engineering.

Keywords: Aerospace design engineering, semantic knowledge management, ontology

1 INTRODUCTION
Aerospace engineering is considered to be one of the most advanced and complex branches of engineering. The complexity of designing and manufacturing flight vehicles requires careful understanding and balance between technological advancements, design, management and costs. Thus, the appropriate capture, structure and dissemination of tacit knowledge within this sector has become imperative to manage and maintain in order to remain competitive and retain both design and manufacturing engineering experience built up over many decades.
Figure 1 illustrates the various phases of the product development life cycle [1]. According to Whitaker in 2005, product development is described as the product-creation process which initiates from the concept phase until it is transformed into a detailed set of instructions for manufacture and assembly [2].

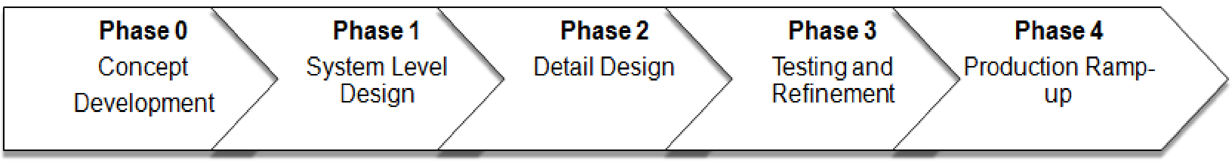

Figure 1. Phases of Product Development Life Cycle [1]

The ongoing collaboration of multidisciplinary specialist skills is of necessity for the development of advanced and complex products throughout the aerospace sector. Two of the key specialist disciplines within this market are design engineering and manufacturing engineering. Collaboration between these disciplines is crucial to the cost-effective and timely development of a product. Furthermore, in a highly competitive market, there is a need to integrate both disciplines in order to improve the efficiency and effectiveness of the product development lifecycle and satisfy customer requirements whilst improving customer satisfaction.
In addition, there is a need to improve the quality of key design engineering competencies in order to adopt a more integrated approach to design and manufacture. It has been established that some of the

main challenges in achieving this are known to be structuring, managing and maintaining knowledge in order to maximise benefit from utilisation of such knowledge in support of product development.

Knowledge is domain-dependent. Therefore, it is limited to its diversity and specificity. This means that it is difficult to tailor knowledge for general purposes. A framework is then needed that will allow for the appropriate construction and generalisation of all forms of knowledge, thus improving the automation and adaptability of all acquired knowledge sources within design engineering processes.

During the past decade, the revolution of the Internet has changed the way in which communication occurs between various teams. However, the biggest challenge faced with the Internet is that its core foundation is solely based on syntax. Research has proven that 'Semantic Web' will be the evolution of the current World Wide Web, an Internet whereby machine is able to understand language due to the definition of ontologies. The definition of ontologies is crucial to developing semantic applications. Research has proven that the use of ontologies aims to model a specific domain in a generic manner. That identifies an adaptable and generic feature [3].

This paper seeks to identify the challenges in semantic knowledge management for the aerospace design sector. It is important to understand how ontological engineering for semantic technology can be used to enhance the management of knowledge within design engineering, limitations of semantic technology and challenges of semantic knowledge management within the design engineering sector.

2 METHODOLOGY

An initial literature review along with a series of discussions with key participants at the aerospace design engineering sponsoring company has been conducted. These discussions were organised as workshops and the purpose was to discover how manufacturing knowledge could be used to enhance design engineering activities. These workshops were undertaken in an open-manner in order to identify and capture knowledge of experts without presumption of the challenges that hinder adequate knowledge management. This initial interaction has led to the idea of developing an efficient and effective approach for knowledge systematisation. It was established that improving the structure and representation of knowledge would benefit and increase the competency of design engineering activities. In support, there is need for researching new areas and considering future technological advancements.

Participating experts from the design engineering function included a knowledge based engineer and design engineering experts who strongly interface with manufacturing engineering. Furthermore, in order to broaden the captured opinions, an initial literature review has been undertaken in order to identify the challenges of developing a semantic knowledge management discipline within the aerospace environment. The initial review revealed the current limitations within semantic technology and challenges of implementing a semantic knowledge based framework within the aerospace sector.

3 RELATED RESEARCH

3.1 Ontological Engineering for Semantic Knowledge Management

Many authors suggest that the foundation of ontologies originated from philosophy [4]. However, ontologies are increasingly being used in many engineering and scientific domains. This view is also supported by Devedzic [5]. He further suggested that ontological engineering comprises of a set of activities such as philosophy, metaphysics, knowledge representation, knowledge sharing, knowledge re-use, business process modelling, design rationale of a knowledge-base and knowledge accumulation. Ontological engineering allows for one to bridge comprehension gaps and to understand both familiar/un-familiar concepts and practices in a different perspective.

The definition of ontology was originally stated in 1993 by Gruber and was defined as a way to support the sharing and reuse of represented knowledge within Artificial Intelligence systems. An ontology is a formal specification of a shared conceptualisation of a domain that is of interest to a particular group of users [6]. An ontology provides a controlled vocabulary of concepts and expresses the associations between concepts. This extends the subject based classification approaches due to its open vocabularies and open relationship types [7].

In addition, Mizoguchi and Kitamura [8] suggest that one of the most promising uses of ontological engineering is that it enhances knowledge systematisation. This systematisation is not necessarily about representing knowledge. The authors suggest that something more clear and concise is needed beforehand, namely that knowledge is structured and organised in an appropriate manner with

appropriate vocabulary. The authors argue that this structure is needed in order to bring forth the next generation of knowledge base building, and ontological engineering is a prerequisite for this vision.
Furthermore, the authors argue that ontological engineering is the successor of knowledge engineering [8]. Ontological engineering allows for a common-vocabulary, well-justified data structure and semantic interoperability that allows for the rapid exchange of information.
Knowledge is known to be domain-dependent, thus establishing a shared agreement of meaning within knowledge engineering is difficult due to the diversity of possibilities in how knowledge is interpreted. However, ontology is different in that it enhances knowledge engineering by identifying its origin and elements from which knowledge is constructed. Kogut and Heflin suggest that in order to implement ontological engineering, one must think declaratively, which means in an Object Oriented manner, rather than the traditional procedural or algorithmic approach [9].
Figure 2 illustrates the core principles of ontological engineering [5]. This is the underlying principle of how an ontology is constructed as agreed by many authors [3] [10]. The four main elements of the ontological engineering discipline are as follows: Basic topics, design, development and applications. The subsection of each element has been expanded within the mind map in Figure 2. However, a more in-depth ontological model will encompass further additional features.

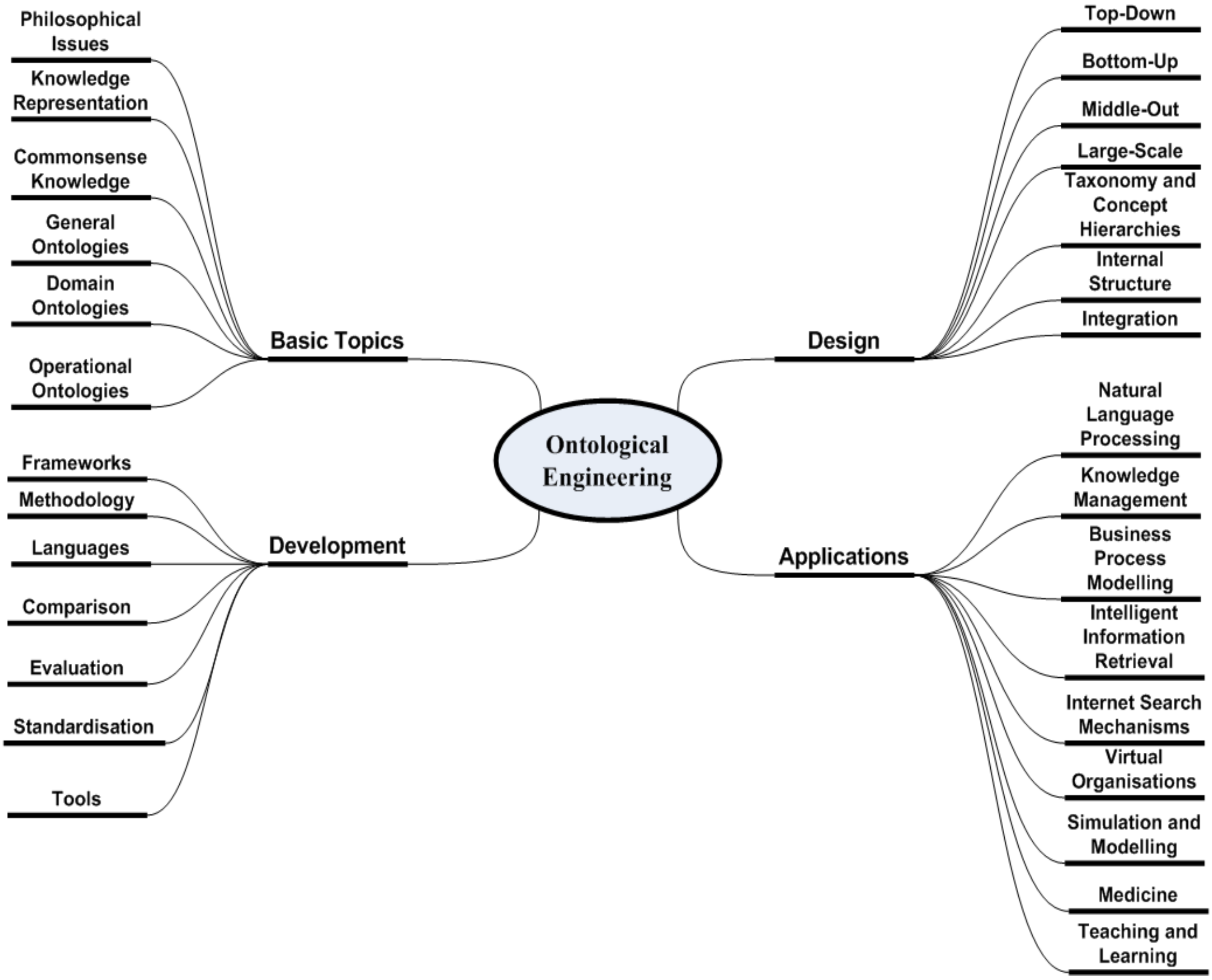

Figure 2. Core Principles of Ontological Engineering [5]

3.2 The Challenge of Semantic Web Technology
In order to understand the challenges of the 'Semantic Web', it is imperative to understand the current limitations of the current web. Horrocks and Bechhofer described the current web as 'Syntactic Web' meaning the foundation of the current web is based on the grammatical arrangement of words in a sentence [11]. The authors identified that information on the current web is designed only to be

consumed by human beings and is not bound to automated processes. The authors emphasised that the current web is all about presenting information and not about the semantic content.

Tim Berners-Lee, whom many credit for coining the term 'Semantic Web', stated in 1999 that the semantic web would not replace the current World Wide Web (WWW); however, it will be an evolution of the WWW [12]. The concepts that govern the semantic web have increased enormously and now being extended and applied in other areas (i.e. medical and pharmaceutical, telecommunications, government) and within stand-alone software systems.

One of the key challenges with semantics is the lack of rich and adequate ontologies. This is a problem currently facing the semantic web community due to the fact that ontology development requires background knowledge. That includes understanding and analysis of the domain [10]. Furthermore, many authors argue that the success of semantics lies within the collaborative development of ontologies [5] [13]. This means that rather than considering it as an activity carried out by an ontological engineer, multiple experts with knowledge on the domain ontology should jointly be involved in the development. This explains why there has been lack of rich ontologies. Furthermore, many researchers have suggested the issue of the ever-evolving language such as expanding synonyms, homonyms, acronyms. In addition, Devedzic suggests that there are many complementary characteristics that exist between the object oriented approach and ontological engineering [5]. Many software practitioners understand the similarities between these two disciplines but there is no clear distinction between them and few have been utilised in practical development. Thus, there is no standard notation for defining ontologies and ontological engineers currently adopt their own notation, unlike the standardised Unified Modelling Language (UML), which is utilised for the Object Oriented Paradigm (OOP) [5]. Many authors [4] suggest that UML could also be adopted to represent an ontology. Research has demonstrated the use of UML for ontology representation. However it has been identified that UML does not capture all the details that should be represented in an ontology in a way that the OWL (Web Ontology Language) does. This suggests that a more advanced notation is needed for the representation of ontologies.

4 THE CHALLENGE OF SEMANTIC KNOWLEDGE MANAGEMENT IN AEROSPACE DESIGN ENGINEERING

The efficient and effective management of knowledge due to the complexity of products within the aerospace sector is becoming increasingly important. The efficient management of knowledge is driven by the continual requirement from customers to reduce timescales, the complexity of the product and associated design tasks and the geographical distribution of engineers.

The challenges in semantic knowledge management within a design engineering environment have been classified into three themes. The first theme is human and organisational issues, which is solely related to people management skills; the second relates to technological issues and the third relates to integrating complexity, as illustrated in Figure 3.

It has been identified that engineers are sometimes reluctant to share documents. This issue is highly detrimental to achieving effective knowledge management. Furthermore, one of the main constraints that have hindered the development of semantic knowledge management within design engineering has been the efficient access to and sharing of knowledge and expertise. Often, experts who are required to demonstrate this competency in problem solving work within a specific domain and are distributed geographically. Subject matter experts could also leave the company or be redeployed at short notice. As a result, engineers often spend large amounts of time searching for a solution to problems that may have been solved. This results in increased time-to-fix, downtime, and significant unnecessary increase in cost.

McMahon, Lowe and Cullet [14] suggest that depending on complexity, there are still challenges that highlight the extent to which design processes may be automated. Through the interaction with the case study company, the interviewed experts identified that although there is a strong capability in modelling and defining product characteristics and representing organisational structures for engineering data, there is still a need for a general and shared agreement of meaning between domain experts and end users. This challenge highlights the benefit of using semantic knowledge management. The use of acronyms, synonyms and homonyms has become an accepted phenomenon that has been applied within both design and manufacturing engineering over many decades. There is obviously a need to take a step back to capture the consequences of utilising some of these vocabularies and understand the effect it has on activities. There is also a need to manage the vocabulary utilised by both design and manufacturing engineering in order to allow for a shared agreement of meaning. Other major issues, such as adequate knowledge management, were also identified as a barrier for encoding, automating and integrating product and process knowledge within knowledge based systems. Furthermore, Information Technology has always been an enabler of knowledge management. One of the challenges of IT for semantic knowledge management suggests lack of open-source tools to support collaborative development, which means there is no interface to a shared environment between design engineers. The utilisation of open-source tools would enhance the communication of both design and manufacturing engineers who are distributed geographically, thus improving and cultivating a shared agreement of meaning between participants. Furthermore, within design engineering, it was identified that there are vast amount of legacy data distributed in various formats. The issue of competent integration is perhaps the most important element that affects the use of technological advancement for knowledge management within the aerospace design environment. In addition, other barriers to knowledge management within design engineering included inconsistent data formats and lifespan of computerised systems. It was also identified that design engineers are not aware of all of the knowledge management tools that are available for the construct and systematisation of knowledge. Additionally, there is a need for automated knowledge classification tools. Evidence in industry has shown that engineers do not want to be burdened with the task of knowledge classification or annotating the semantic contents of a document. This further illustrates the importance of acquiring a dedicated knowledge/ontological engineer that will be responsible for such an activity. Furthermore, design engineers would ideally better understand the benefits of structuring and managing their knowledge in ways that will increase the degree of re-use.

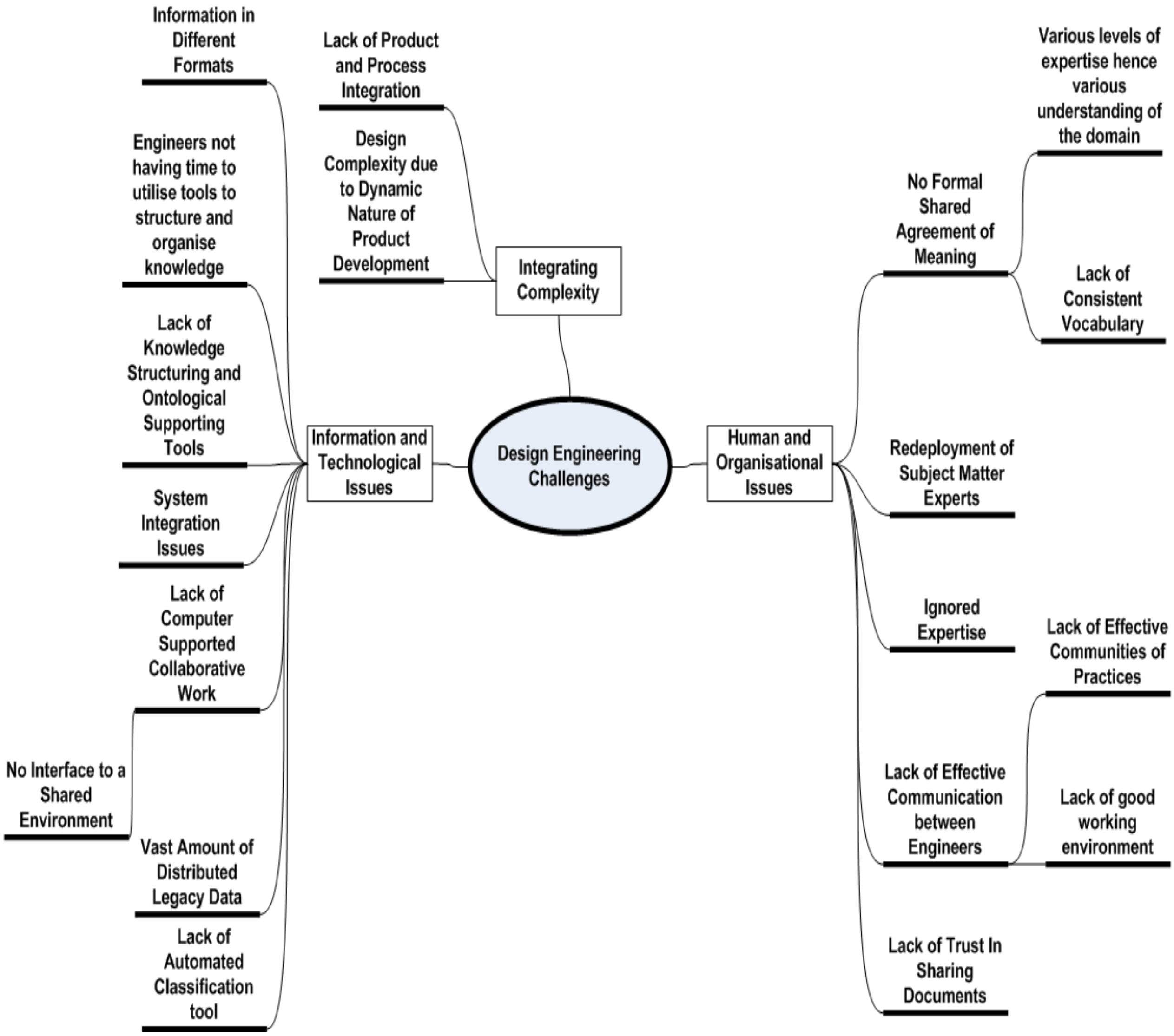

Figure 3. Challenges of Semantic Knowledge Management in Aerospace Design Engineering

4.1 Human and Organisational Challenges

An illustrative scenario within the aerospace engineering industry for producing gas turbine systems is used to discuss few of the elements in the mind map. The manufacture of holes on the combustor wall (part of a gas turbine engine) has been selected and the preliminary design stage of the combustor product development process has been captured to help understand the domain.

One of the major issues is a lack of a shared understanding of meaning between both design and manufacturing engineers. This is due to the subjective and domain-dependent nature of knowledge. Interviews and workshops conducted in the aerospace industry have demonstrated that the barrier of miscommunication between both design and manufacturing engineers is a people issue rather than an IT issue. This is inherently due to the diversity of individuals, different perspectives and inconsistent use of vocabulary. This has made it more difficult to develop a shared understanding of a given domain between a group of users.

After the development of an initial ontology, experienced design and manufacturing engineers contributed towards enhancing the vocabulary of the domain ontology with a view to develop a common understanding of meaning. To illustrate a scenario, one of the concepts within the domain ontology was defined as ‘Tool’, it was identified that the term ‘Tool’ in manufacturing engineering is described as a physical manufacturing device (e.g. Chipless machining). However, the term ‘Tool’ in design engineering is often thought to be computer software, excel spreadsheet with macros or even a design method. Due to the variety of meanings and context, it was identified that the term ‘Tool’ is not a suitable name for a concept within the domain ontology and this term was changed to the term ‘Software’ which was the term agreed and shared between both the design and manufacturing engineers. In addition, a particular term within design engineering that is commonly used is the term ‘generate analysis’. After discussion with engineering and knowledge management experts, it was identified that there are several meanings and interpretations from this term (i.e. assess model, run model, view model results, set-up model, etc). This signifies the need for a change in the use of vocabulary.

In another scenario, it was discovered that inspection processes are usually considered as manufacturing processes. However, after a knowledge capture session with engineering experts, it was identified that reverse engineering is possible, which means a component could be inspected before manufacture so inspection processes are actually not part of manufacturing processes and are independent entities on their own. Furthermore, various level of expertise exists within the aerospace domain hence various understanding and interpretation of the domain. This means what is considered as information to an experienced engineer could be considered as knowledge to an inexperienced engineer. This suggests it might be more complex to develop a shared understanding of meaning between engineers with different expertise hence identifying, understanding and categorising levels of expertise is essential.

4.2 Information and Technological Challenges

One of the major issues is the challenge of structuring and categorising knowledge within the aerospace domain. New knowledge will always be produced and captured as a result of new challenges and experience. There is need for a systematic approach that will allow for the capture, structure and dissemination of knowledge to engineers. The use of an ontology is a simple but powerful way to achieve this, however there is need for software that will automatically structure captured knowledge without requiring manual input from engineers seeing as it has been identified that often engineers are too busy with design and manufacturing activities and often do not understand the benefits of structuring and managing their knowledge. There is need for software that will allow for the automated classification of domain knowledge.

In addition, due to the vast amount of distributed knowledge, there is need for improvement in search mechanisms. It was discovered that engineers often struggle with locating best practice knowledge for a specific engineering problem. A semantic search engine will help in improving search accuracy by understanding the meaning of terms. This will improve the accessibility of distributed content and engineers would generate more relevant results, which will significantly reduce the time it takes to search for contents on the web.

4.3 Integrating Complexity Challenges

Within the design engineering environment, it is complex to integrate product and process knowledge. The design and manufacture of a product is taken through various stages of engineering processes. During these stages, knowledge is produced and consumed; it is essential that previous knowledge is applied and reused in these engineering processes. However, due to design complexity and the dynamic nature of product development, it is often difficult to reuse know-how knowledge. There is need for a systematic approach to aid the integration of process and product knowledge within aerospace engineering. There are many different approaches and processes an engineer may take in the development of a component; however, there is no standardisation of design and manufacturing processes and if one exists, it is often difficult to follow due to the dynamic nature of product development. During the product development stages, best practice knowledge is identified due to new challenges and experience; however, this is not often captured and structured in the right manner to reinforce reusability. It is essential to find new approaches to capture manufacturing knowledge and feed back to design activities in order to have a more integrated approach to design and manufacture as this will have a significant impact on product quality, lead time and cost.

5 CONCLUDING REMARKS

This paper has described the challenges of developing a semantic framework within the aerospace design engineering sector. There is a need to more effectively structure and manage complex knowledge within design engineering. In order to achieve this, an effective and proven approach must be considered. Semantic technology reinforces the re-usability, flexibility and maintainability of knowledge and its management. The use of ontological engineering for semantic knowledge management has been quantified and implemented in real world settings resulting in significant benefits. However, the literature review has suggested that there is currently no standardised notation for representing ontologies. Evolving vocabulary also poses a challenge to the use of semantic technology. Various factors within design engineering could hinder the effective application of semantic technology within this sector. For example, no formal shared agreement of meanings, under-valued expertise and design engineers not having time for the task of utilising ontological tools to structure and represent design domain knowledge.

Further work could include an attempt to develop a formal representation for ontological engineering in order to identify and resolve issues currently within the UML notation for OOP. In addition, the importance of collaboratively developing an ontology with domain experts has been suggested as an effective means of developing a semantic framework that could be tailored to different design engineering processes.

ACKNOWLEDGEMENTS

The authors would like to thank the Engineering and Physical Sciences Research Council (EPSRC), and the industrial sponsor (Rolls-Royce Plc) for funding this research project.

REFERENCES

[1] McManus, H. L. *Product Development Value Stream Mapping (PDVSM) Manual.* 2005. (Massachusetts, Cambridge: Massachusetts Institue of Technology).

[2] Whitaker, R. B. *Value Stream Mapping and Earned Value Management: Two Perspectives on Value in Product Development.* 2005. Master Thesis in Engineering and Systems. (Cambridge: Massachusetts Institute of Technology).

[3] Uschold, M. Ontologies Everywhere - but Who Knows What to Think? In 9th *International Protege Users Conference* California, July 2006, pp. 4-54. (Standard CA, Phantom Works).

[4] Kokar, M. M., Matheus, C. J., Backlawski, K., Letkowski, J. A., Hinman, M., and Salerno, J. Use Cases for Ontologies in Information Fusion. In *Proceedings of the 7th International Conference on Information Fusion*, Vol. 2, Sweden, July 2004, pp. 415 - 422.

[5] Devedzic, V. Understanding Ontological Engineering. *The Communication of the ACM.* 2002, 45(4), pp 136-144.

[6] Gruber, T. R. *A Translation Approach to Portable Ontology Specifications. 1993* (John Wiley & Sons, Chichester).

[7] Sanya, I., Shehab, E., Roy, R., Houseman, O. and Jonik, M. Semantic Based Approach for

Product Maintenance Support. *CIRP proceedings of the 20th design conference,* France: Nantes, April 2010, pp. 90 - 97.
[8] Mizoguchi, R. and Kitamura, Y. *Foundation of Knowledge Systematization: Role of Ontological Engineering, 2000.* (Springer, Verlag).
[9] Kogut, P. and Heflin, J. Semantic Web Technologies for Aerospace. In *IEEE Aerospace Conference,* Washington, March 2003, pp 67 – 73.
[10] Na, J. C. and Neoh, L. H. Effectiveness of UMLS semantic network as a seed ontology for building a medical domain ontology. *Aslib Proceedings* 2007, pp 32-46.
[11] Horrocks, I. and Bechhofer, S. *Semantic Web: Human Computer Interaction Series. 2008* (Springer, London).
[12] Berners-Lee, T., Dertouzos, M. and Fischetti, M. *Weaving the Web: The Past, Present and Future of the World Wide Web by its Inventor. 1999.* (Orion Business, New York).
[13] Dadzie, A. S., Bhagdev, R., Chakravarthy, A., Chapman, S., Iria, J. and Lanfranchi, V. Applying Semantic Web Technologies to Knowledge Sharing in Aerospace Engineering. In *Journal of Intelligent Manufacturing*. 2008. pp 611-623.
[14] McMahon, C., Lowe, A. and Culley, S. Knowledge Management in Engineering Design: Personification and Codification. *In Journal of Engineering Design*, 2004. pp 307-325.

Contact: Essam Shehab
Cranfield University
Decision Engineering Centre, School of Applied Sciences
Cranfield, Bedford, MK43 0AL
UK
Tel: Int +44 (0)1234 750111 x5241
Fax: Int +44 (0) 1234 754109
Email: e.shehab@cranfield.ac.uk
URL: http://www.cranfield.ac.uk/sas/aboutus/staff/shehabe.html

Dr Essam Shehab has developed a strong reputation in research and teaching activities. He has contributed in establishing Cranfield as one of the centres of excellence in Cost Engineering and knowledge-based decision support systems. He has developed new research areas in the application of Knowledge Management to product and service design.