A KBE SYSTEM FOR THE DESIGN OF WIND TUNNEL MODELS USING REUSABLE KNOWLEDGE COMPONENTS

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ABSTRACT

Knowledge-Based Engineering (KBE) has gradually gained prominence as a major tool to speed up product development, especially in large scale projects such the ones that take place in aerospace and automotive industry. The encoding of design knowledge from domain experts into computer codes that can generate complex geometric data has demonstrated significant savings in manpower and time resources for routine design problems. This paper is the experience of the development of a KBE application for the design and manufacture of a wind tunnel testing model of an aircraft nacelle. The industrial project is aimed to investigate the feasibility of KBE introduction in the company. This causes the researcher to achieve effective design task automation and at the same time consider how the KBE codes could be extended to other products in the company. The adoption of reusable knowledge components is then introduced as the response to the knowledge modelling issues in current KBE systems.

1 INTRODUCTION

Among the technologies supporting automated design, KBE has become an accepted tool in the aerospace and automotive sectors. KBE is a special type of Knowledge Based Systems with a particular focus on product engineering design and downstream activities such as analysis, manufacturing, production planning cost estimation and even sales. The technology provides a high degree of design integration and automation in well defined and complex design tasks. KBE makes this possible through the tight integration of an object-oriented programming language and a geometric modeller. Both elements together facilitate an automated way to introduce design requirements, model design constraints and provide a product description. At the same time the know-how and the know-why of the design work that KBE engineers elicit from engineering experts remains stored in the KBE applications (*Cooper et al. 1999*).

Instead of replacing CAD, KBE complements it by offering an environment to automate design activities as well as the means to build an abstraction in which product knowledge is encoded and stored using an advanced programming language. This language is usually based upon the object-oriented knowledge representation paradigm (class objects, inheritance, polymorphism, etc.). KBE systems have embedded the functionality of CAD systems. This means that the encoded knowledge can be interpreted by the system in order to generate product information such as 3D models, drawings and so on.

2 KNOWLEWDGE MODELLING APPROACH IN KBE

Current KBE software systems use a combination of the 'production rules' and the 'object-oriented knowledge representation' as the representation paradigms. As it has been reported by *Bench-Capon,* (*1990*) the combination of both paradigms results in a powerful knowledge representation strategy by combining the flexibility of rules with the capabilities for modelling real problems of object-oriented data structures. The adoption of both knowledge representation paradigms has been widely recognised as highly effective to exploit the benefits of CAD and the feature-based geometric modelling approach, (*Latif and Hannam 1996*).

However, the modelling of product design knowledge is not only a choice of what knowledge paradigm or which language is more appropriate. Given a representation schema the question remains also in how should this knowledge be made explicit using certain modelling schema.

This means that the engineering knowledge has to be correctly structured in KBE application codes. In terms of developing KBE applications, this structuring process involves the configuration of the objects that model the engineering design environment and the rules that control the behaviour of the objects. This constitutes a process of abstraction that in the KBE environment can be stated as follows: "The process in which the engineering knowledge is analysed for being represented in terms of objects and Engineering Rules (ERs) in a computer understandable language". (*Bermell-García et al. 2001*).

The object-oriented technology available in KBE systems allows building class objects containing geometric definitions, cost models or any other useful representation related to the product. The ‘design configuration’ knowledge refers to the particular arrangement of the objects in an engineering problem or a range of domain dependent problems. ERs are units of knowledge that can be identified as constituent components to make up a KBE application. These may be mathematical formulae or conditional statements, and although simple in concept, they may be combined to form complex and powerful expressions, (*Lovett et al. 2000a*)

ERs represent the knowledge that the system requires for taking design decisions. As it is explained in *Soltan* (*1995*), in generic decision situations two factors are needed: information and knowledge. In such decisions, a person reads some information and then uses his knowledge to make a decision. This decision-making procedure is modelled in KBE by using conditional statements. The most common conditionals are the IF-THEN statements although some KBE software systems allow more complex conditional structures.

'IF engine_size = 1000
THEN cylinder_diameter = ((4*1000/π)^1/2)/number_of_cylinders)'
'IF engine_size<500
THEN number_of_cylinders = 2'
'IF engine_size < 500
THEN cylinder-material_steel_1'.

Table 1. ER statements in the example of a car engine design.

Knowledge Management (KM) is becoming an important part of business companies. The role of KBE in KM has to do with the product knowledge management issues. KBE has to facilitate KM operations to store and use product knowledge in order to achieve benefits such as reduced product lead time, reduced knowledge loss and improved design. KBE implementation has achieved these benefits in many industrial cases, (*Cooper et al. 1999*, *Li et al. 2000*). However, research work in KBE has identified that in many of these cases the benefits are only benefits in the short-term instead of in the long-term, (*Sainter et al. 2000b*). According to these authors the long-term problems are the following ones:

- Knowledge loss, due to poor modelling of the applications;
- Knowledge loss, due to the development language;
- Knowledge misuse, due to incorrect selection of the applications being developed;
- Increased maintenance costs, due to the lack of standardisation of applications; and
- Knowledge under utilised, due to the difficulties in sharing and reusing knowledge.

The basic objectives that have to be supported by KBE are: solve a particular design problem by a KBE application (short-term), and retain the domain knowledge required for solving design problems in the same domain (long-term).

However, methods to develop a KBE application in a systematic and structured way in order to extend and maintain it conveniently; and effective ways to reuse the knowledge collected for one KBE application in the future KBE applications are challenging research problems. Research on better methodologies for KBE development can be found in projects like MOKA, (*Klein 2000*). At the application level, example project like KOMPRESSA (Knowledge-Oriented Methodology for the Planning and Rapid Engineering of Small-Scale Applications aims at developing KBE implementation methodologies for small organisations, (*Lovett et al. 2000-b*).

3 WIND TUNNEL MODEL DESIGN

In this research/industrial collaboration project the authors and the KBE group at Cranfield University have been commissioned to build a KBE system to investigate the feasibility of using KBE for aerodynamics wind tunnel model design and manufacture. ARA Ltd., the collaborating company, manufactures and tests wind tunnel models that are scaled down versions of aircraft components. Although computational fluid dynamics (CFD) simulation is used extensively for the aerodynamic design of aircraft, the testing of design using a physical model in a wind tunnel is still an essential step to validate the design. The external shape of the wind tunnel model has to conform to the full size aircraft design. The internal structure of the model has to incorporate all the features for instrumentation and attachment requirements of the test, as well as maintaining a similar structural behaviour of the full size aircraft. Typical wind tunnel test requires the collection of pressure data from a pre-determined pattern of points on the surface of the model. The points are the location of the 'pressure tappings'. Tubes (tubing system) run inside the model to connect the pressure tappings to the pressure measuring instruments (Figure 1).

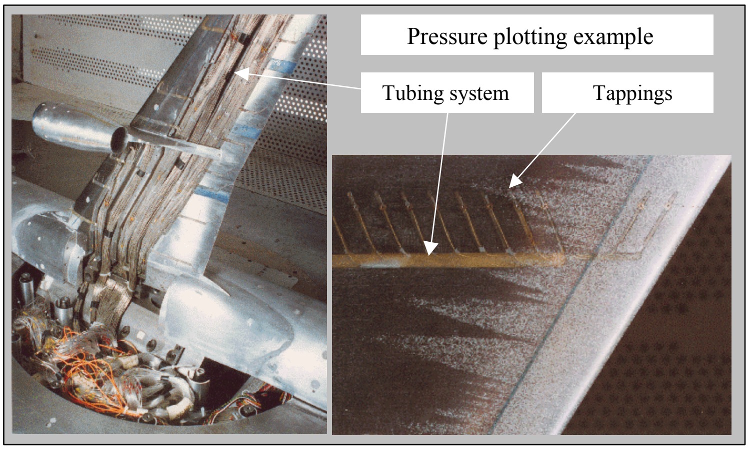

Figure 1. Pressure tappings and tubing system in a typical wind tunnel model component.

3.1 Case study

The case study selected in this KBE implementation consists on the model design of an aircraft nacelle as one of the typical products designed, manufactured and tested in ARA. All the players involved in the development of the project have participated in the selection of the case study. Proper introduction to the KBE technology and detailed information about the products suitable for the implementation of KBE was provided to ARA at the beginning of the project. In this way, the KBE team was able to select an appropriate case study in terms of design configuration and complexity of the product. The implementation tool used in this project was KTI´s ICAD (*KTI 2002*). ICAD provides special support for modelling problems in the product design domain in its ability to deal with geometric data as well as with non-geometric product data. ICAD uses an object-oriented language called IDL. IDL is an object-oriented, non procedural, demand-driven and order independent language based on the ACL LISP implementation.

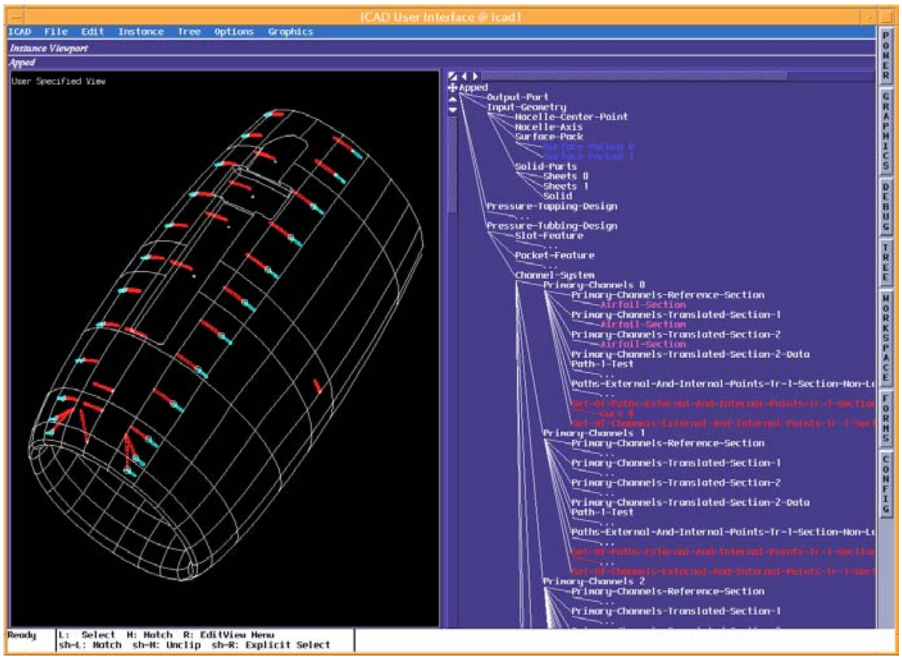

Figure 2. Screenshot of the current KBE application

4 REUSABLE COMPONENTS IN KBE APPLICATIONS

At the KBE encoding level, a knowledge structuring method was developed and tested on the case study to enhance knowledge sharing reuse and maintenance of KBE applications. The result is a formalised way to encode KBE software objects which facilitates their reuse, sharing and maintenance. In this project, diverse KBE encoding strategies were analysed and special attention was paid to their ability to explicitly represent the encoded knowledge and make it accessible to people with no IDL skills.

4.1 Object configuration approach

The knowledge structuring schema relies in a special configuration of object-oriented classes within ICAD KBE codes. Such structuring schema is built through the decomposition of the design task into independent functional units (FU) derived from current design process models. Then, the identified functional units are decomposed into problem-solving models that represent the reasoning to achieve a solution of the problem stated by the functional units. The components inside the problem solving models are instances of objects to be encoded by KBE programmers. An illustration of the functional units and the example of a decomposition of the FU.1 into a problem solving model are depicted in Figure 3.

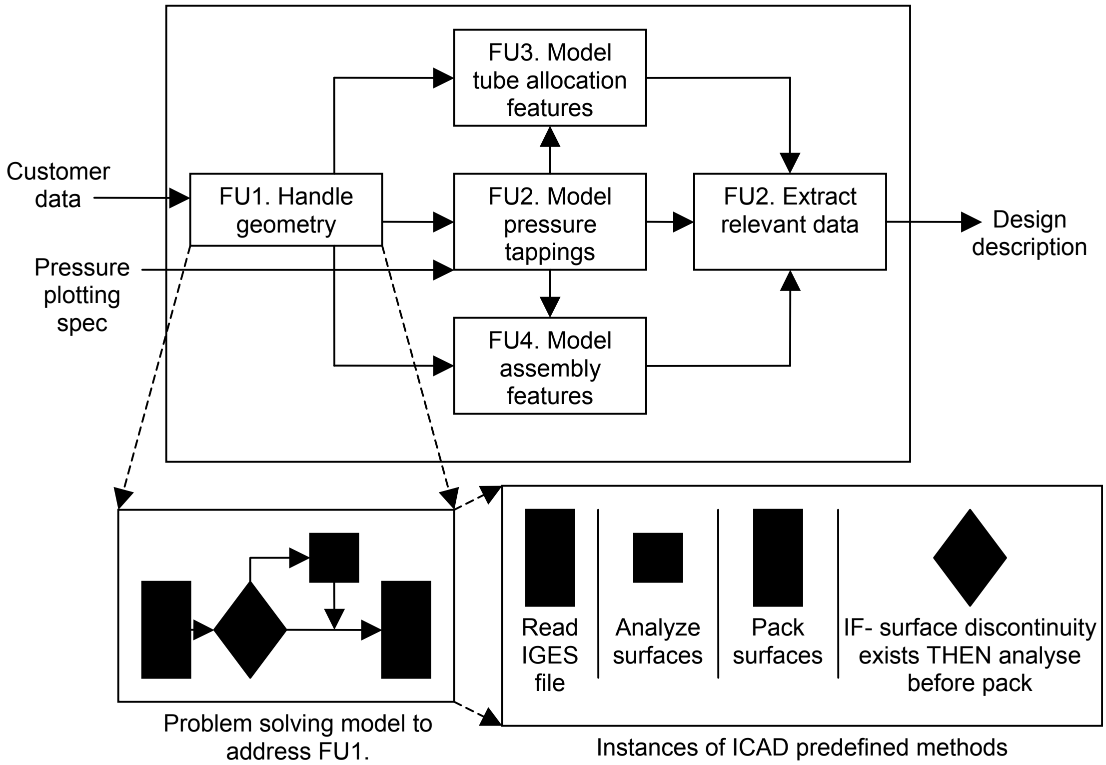

Figure 3. Knowledge structuring schema.

The adopted approach supports the reuse of the problem solving components by enabling the engineering experts with no KBE encoding skills to gain access to the knowledge. Whenever a FU has to be created or updated, the engineering experts configure a set of operations leading to the solution. For this purpose, the encoded software objects are created that conform to a protocol that explicitly represents the inputs and outputs of every component in the KBE application. The specification of the problem solving model by engineering experts therefore has to be complemented with an analysis of the requirements in terms inputs and outputs of the software components that will be instantiated. The problem solving model may consist of just a sequence of design operations or it may require the application of some reasoning by the inference of ERs. The knowledge structuring schema handles ERs as special entities and explicitly represents them to enable their management by people with no IDL skills. This capability is available by the use of a rule level knowledge management system specifically developed for ICAD´s KBE applications. Detailed documentation about such system can be found in *Fan et al. (2002).*

Finally, the specification is delivered to the KBE programming experts who will is responsible to encode the components and the ERs by using the particular KBE coding strategy.

Figure 3 illustrates the capabilities of the knowledge structuring method to separate as much as possible the tasks that require the knowledge of engineering experts from those that need the knowledge of KBE programming experts. In the example of solving the problem of importing the customer geometry into the KBE application, the engineering experts with no ICAD skills use their knowledge to elicit the FU required to achieve the wind tunnel model design. Then, the experts use their knowledge to specify a problem solving model required to handle the geometry of the component provided by ARA´s customers. Finally, this problem solving model is passed to the ICAD expert who will use his IDL knowledge to bring the geometry from an IGES file into the system in the most reliable way.

Although this structuring approach helps to separate the work that requires ICAD skills from the work that does not, the collaboration among both knowledge sources is essential. Thus, the border of the duties of both types of experts is not clearly defined. The experience gained in developing the KBE applications shows that engineering experts must be aware of the possibilities as well as the limitations of the KBE technology.

5 CONCLUSIONS

Most KBE applications have been developed for solving large design problems in the aerospace and automotive industries where the main concern is the functionality to automate a complex design problem, rather than the reusability of engineering knowledge. It has to be made cleared at this point that the immediate cost for the development of a reusable KBE application can be more than the cost to develop a bespoke KBE application. The benefits of the reusable concept are to be reaped from the elimination of redundant knowledge capture and the systematic build up of a high quality knowledge pool for long term KBE implementation.

The implemented KBE application demonstrated the feasibility of using KBE technology in the particular domain of wind tunnel model design. It was reported by ARA that the design work performed by the application in a session of two hours would take up to two weeks of repetitive and slightly variant modelling tasks.

The long term benefits of the structuring approach are expected to be significant in future KBE developments on the domain. The structuring schema enhances the knowledge sharing capabilities of KBE applications by enabling no IDL trained people to access to the knowledge stored in upper levels of KBE codes. (The simplification of the upper level objects makes them understandable to non ICAD skilled persons).

The maintainability of KBE applications encoded by using this strategy has been enhanced significantly. The decomposition of FU into problem solving models was updated several times during the development of the KBE application. The structuring schema showed that the re-engineering of components at the problem solving level was a process of adaptation more than a process of rebuilding new components as usually happened in other structuring methodologies. (As a matter of fact the FU1 component, formerly composed by a sequence of operations was re-engineered by adding ERs when the need of analyse the surface patches came up.)

Further research work is being performed to address the knowledge structuring problem in wider scope and more deficiently defined design problems than the wind tunnel design. Consequently, powerful ways of representing problem solving and domain knowledge are under investigation. Promising technologies to address these issues are ontology engineering at the human understanding level and UML at the machine interpretable level.

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