Advanced Engineering Informatics 26 (2012) 219–230

Contents lists available at SciVerse ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

A framework for management of Knowledge-Based Engineering applications as software services: Enabling personalization and codification

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ARTICLE INFO

Article history:
Received 28 February 2011
Accepted 30 January 2012
Available online 24 February 2012

Keywords:
Knowledge Based Engineering
KBE
Personalization
Codification

ABSTRACT

Literature on Knowledge-Based Engineering (KBE) has identified challenges concerning the personalization and codification of knowledge for new product development, such as maintaining the quality, accessibility and traceability of knowledge for inspection, review and re-use, as well as managing the life-cycle of KBE applications and the knowledge contained within these applications. This paper reports on the development of a framework that realizes the management of Knowledge-Based Engineering (KBE) applications as software services, and in doing so supports the codification and personalization of knowledge that is used in performing knowledge-intensive product development tasks. The developed framework supports the elicitation and structuring of design and manufacturing knowledge, provides the capacity to run KBE applications as remote software services, and facilitates the distribution and lifecycle management of KBE applications and the underlying knowledge. A 'learning by doing' approach is supported where knowledge can both be personalized and codified as design progresses and new insights are gained. The framework has been successfully applied in an industrial use case that considers the conceptual design of composite aircraft wing covers.

1. Introduction

When considering the domain of aerospace engineering, the development of aircraft is a highly complex, collaborative endeavor in which knowledge from numerous stakeholders and disciplines must be integrated to come to a design. In tandem with the introduction of new materials and production techniques, the development of design methods and applications is a must – design engineers must be supported in 'learning by doing'. Within this context, it must further be ensured that the time spent on the conceptual design of aircraft is reduced to meet ambitious development requirements, however without sacrificing the quality of concept analysis. The use of Knowledge-Based Engineering (KBE) applications may prove to be a significant step towards achieving these objectives [1] through the possibility of engineering automation while retaining the requisite knowledge [2,3]. This may reduce design time significantly while improving quality of design analysis, decisions and output. However, there are currently quite a few research challenges associated with KBE development [3], some of which focus on the topic of personalization and codification of knowledge [4]. In particular, research must find a way to support a 'learning by doing' approach: many current aircraft design projects, in their switch towards the use of composite materials, are gaining knowledge about design while designing: designers are 'learning by doing' [5]. From this perspective, developed solutions must be able to store new knowledge that is gained while developing products, but also flexibly apply this knowledge in associated design tools and applications – successful codification is a must. Furthermore, existing knowledge must be able to be updated following new insights, without impacting design tools that rely on this knowledge to operate. As such, the life-cycle of the knowledge, but also of the associated design tools, must be managed. Finally, to successfully support 'learning by doing', the knowledge must be personalized: it must be geared towards the end user(s), which must be able to retrieve, understand and if necessary, update the knowledge used for design and analysis.

Within this context, the objective of this paper is to present a framework that realizes codification and personalization of knowledge-intensive product development tasks. The developed framework supports the deployment and use of KBE applications as elements in modular knowledge packages (Enterprise Knowledge Resources, or EKRs [6]) that are managed in a central knowledge repository, and can be deployed to perform tasks in support of an automated conceptual design process. These EKRs are set up

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doi:10.1016/j.aei.2012.01.006

for specific design or analysis tasks and contain KBE applications, the underlying codified knowledge elements, a workflow representation and a set of case reports. The novelty and contribution of this work lie in the articulation of the principles and components that were used to develop the framework for personalization and codification of knowledge-intensive product development tasks, and in the example of how this framework can be implemented in practice. The latter is achieved through the discussion of a use case which considers the integration of manufacturing considerations within conceptual design of ply stacking sequences for composite wing covers. It will be shown that through the use of this framework, designers can use personalized and codified knowledge to execute design tasks automatically, which ensures reduced design time through the use of KBE applications while ensuring the quality of knowledge through lifecycle management of the knowledge associated with the KBE applications.

This paper is organized in the following manner. First, a brief description of the industrial context and the identified research challenges is given. This is followed by a discussion of the main concepts and principles underlying the proposed knowledge framework, followed by notes on implementation aspects. In Section 4, a use case is presented where the proposed knowledge framework is implemented for the optimization of ply stacking sequences in composite wing cover conceptual design. Finally, the achieved results are briefly discussed, after which concluding remarks are given.

2. Research background

This section describes the industrial context of the research reported in this article, which subsequently drives the identification of research challenges that this paper will address.

2.1. Industrial context

The research reported in this paper has been carried out in the context of the development of a new generation narrow-body civil aircraft, the Airbus A30X, pitched as an eventual successor to the A320 family of narrow-body aircraft. According to Airbus, A30X is to enter the market in the late 2020s [7].

Although the market availability of the A30X aircraft is at least 15 years ahead from today, the complexity of an aircraft program forces research and technology development efforts to be started well in advance. Broadly speaking, the two main work streams to develop the A30X program are:

- **Conceptual design studies** to identify the optimum configuration of the aircraft to satisfy the forecasted market needs. In this work stream, Airbus is evaluating novel aircraft configurations including forward-swept wings, rear-mounted turbofans and vertical tail planes among others [8].
- **Engineering capabilities** to effectively address technological challenges emerging from the new program. While the previous work stream focuses on design, this one aims to realize the necessary technology innovations that will achieve the market claims of the new aircraft (i.e. high fuel efficiency, low production cost and others). Examples in this direction include the development of new generation engines and the development of new design and manufacturing technologies to support the use of thermoplastic-based composites [9].

This distinction highlights the point that aircraft development projects not only involve a design effort looking for new concepts, but also a research effort to identify and develop novel technologies to achieve requirements. Contemporary industrial policy aims to encompass these two aerospace product development work streams through collaborative research projects. In the United Kingdom, an example of such a project is the Next Generation Composite Wing (NGCW) project [10], in which Airbus UK and EADS Innovation Works work with several major industrial and academic partners to research materials, technologies and tools to support the design and manufacturing of composite wing structures. As part of the NGCW work package, the Multi-Disciplinary Optimization of Wing (MDOW) research project has been initiated to research and develop design tools for the multidisciplinary analysis and optimization of wing structures. The work reported in this article has been carried out as part of the MDOW project.

2.2. Multi-Disciplinary Optimization in distributed environments

Multi Disciplinary Optimisation (MDO) is a well-accepted strategy to achieve the development of complex products by encompassing the inputs and objectives of multiple disciplines and stakeholders [11–14]. The concept is applied in the MDOW project to realize an engineering capability consisting of a framework of interconnected design methods and tools to effectively optimize wing configurations by:

- Supporting aircraft architects to speed up the generation of feasible aircraft concepts.
- Supporting engineering experts in the relevant disciplines such as aerodynamics, structures, manufacturing and others to make well-informed evaluations of these concepts by using their domain-specific knowledge, methods and tools.

A key to the success of this project is to manage the work of engineering design teams and the flow of design concepts information between engineering disciplines in highly distributed environments. This requires the effective management of engineering teams who are often disconnected by their expertise domain, as well as other barriers (e.g. geographical separation). An additional (and related) factor in conceptual design is the ability to cope with increasing amounts of data and knowledge. Typically, data and knowledge regarding a product design is distributed over the company; it can be excessively difficult to adequately share and use this knowledge across the company [4,5], with compatibility of and interaction between design tools, analysis tools and data and knowledge enterprise repositories being notoriously complex to manage [15,16].

To be effective in aircraft conceptual design, MDO must accommodate two primary perspectives: top-down and bottom-up – see also Fig. 1. A top-down view considers aircraft designers who have to make fast and informed decisions regarding the performance of aircraft concepts. Typical performance indicators used at this level include, amongst many others, aircraft mass, drag and power. Aircraft designers use these indicators to study the best design configurations to achieve the product requirements. In a bottom-up view, the individual discipline teams (such as the manufacturing discipline, as illustrated in Fig. 1) analyze design concepts from their particular perspective in order to provide quantified indicators on the performance of the concept being analyzed. These studies provide estimations on aspects such as the minimum weight for an aircraft structure and the industrial capabilities to manufacture aircraft concepts.

The performance of the conceptual design process can be assessed by two key indicators. First, from a top-down perspective the time necessary for evaluating concepts is a key indicator: bringing this time down allows for more extensive exploration of the design solution space, which may lead towards a more optimal design solution. To achieve a reduction in time necessary for evaluation of aircraft concepts, a seamless integration is required of