Knowledge-Based Systems 84 (2015) 89–97

Contents lists available at ScienceDirect

Knowledge-Based Systems

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

Transforming expertise into Knowledge-Based Engineering tools: A survey of knowledge sourcing in the context of engineering design

S. Quintana-Amate [a,b,*], Pablo Bermell-Garcia [a], A. Tiwari [b]

[a] Airbus Group Innovations Technical Capability Center 5 (Systems Engineering, Information Technologies and Applied Mathematics), Golf Course Lane, Filton, Bristol BS997AR, United Kingdom

[b] Manufacturing and Materials Department, School of Applied Sciences, Cranfield University, Cranfield, United Kingdom

ARTICLE INFO

Article history:
Received 23 October 2014
Received in revised form 11 February 2015
Accepted 1 April 2015
Available online 4 April 2015

Keywords:
Knowledge-based engineering
Knowledge sourcing
Knowledge acquisition
Knowledge capture
Knowledge reuse

ABSTRACT

Research on Engineering Knowledge Management (EKM) has identified challenges with the systematic source of engineering knowledge for the design process optimisation. In this context, Knowledge-Based Engineering (KBE) is acknowledged as a key area within the EKM field and designated by the research community as a potential solution to carry out the effective capture and reuse of expert knowledge. However, papers on KBE for knowledge sourcing are not abundant in the literature and they are also dispersed. From this perspective, this research is an effort to further consolidate the learning gained on industrial practice on how engineering knowledge can be effectively sourced. This is achieved by realising a research survey, where using the resulting insights KBE practice reaching aerospace engineering offices shall be more efficiently delivered through fast and accurate knowledge extraction and encoding into usable methods and tools. The research findings provided by literature survey confirmed the existence of a research gap on knowledge sourcing; and more precisely they underlined the need for an extended KBE development process which integrates Artificial Intelligence (AI) tools and expert intervention to systematically manage the knowledge (using the KM methods and tools) efficiently captured and modelled (employing AI algorithms and expert involvement). Therefore, this paper concludes that there is a need for further research on the knowledge sourcing KBE aspect and presents the integration of KBE systems and AI implementations as a potential solution to develop the extended KBE development process requested by the industry.

1. Introduction

Engineering design has been traditionally described in mainstream methodologies as a systematic process consisting of a prescribed workflow moving product development from conceptual to detail design [1–3]. A more information-oriented view of this design process is the multistep process described in [4], where design steps transform ideas into the information required to create a product.

The complexity of the design problems faced by engineers in the aerospace domain forces them to focus on their specific domain task while maintaining visibility to the task from other domains in order to make balanced engineering decisions. By addressing this challenge efficiently, designers shall have fast access to the relevant information required to carry out their job. The consequence of an optimised decision-making process in design is the reduction on the number of iterations required to produce successful designs. The immediate effect to competitiveness is the reduction of design lead time and costs while maintaining the quality of the product developed.

The context of this research is the aerospace industry where high pressures are becoming apparent in the need to increase the financial returns on the investments made in engineering expertise. A feasible route for engineers to optimise the design process information flows is the adoption of Engineering Knowledge Management (EKM). The concept is presented in [5] as *"a key for the organisations attempting to capitalise their expertise and know-how"*. Other authors point out in their EKM definitions to the systematic process in which knowledge is organised in an efficient manner facilitating its exploitation and reuse [6,7]. In this direction, the work reported in [5] illustrates that the speed in making the right decisions at the design stage is essential since it influences around 80% of the end product cost. Recent research carried

* Corresponding author at: Building 20A1, Golf Course Lane, Filton, Bristol BS99 7AR, United Kingdom. Tel.: +44 (0)163 371 4653, +44 (0)742 862 7410.

E-mail addresses: Santiago.Quintana@Airbus.com, q.a.quintanaamate@cranfield.ac.uk (S. Quintana-Amate).

http://dx.doi.org/10.1016/j.knosys.2015.04.002
0950-7051/

out by the authors in the context of multi-disciplinary optimisation highlights the benefits from managing and disseminating manufacturing engineering knowledge (manufacturing constraints) as a strategy for informed decisions on aircraft wing design choices [7]. Key insights gained from this research are: (a) making the knowledge from manufacturing experts available to engineering designers facilitated the adoption of manufacturing considerations in the design and; (b) transferring the knowledge into software transforms the knowledge into actionable methods and tools that can be exploited to support the design process more efficiently.

An approach to realise this knowledge elicitation and encoding into tools has been often described in the literature as Knowledge-Based Engineering (KBE), [8]. The authors have identified that reported research on KBE usually focuses on the methods and tools supporting the transformation of the knowledge into computer code. However, a research gap is perceived by the industrial researchers on the methods and tools that can be used to effectively source the knowledge acquired and encoded in the KBE development process. The main aim of this paper is to further consolidate the learning gained on industrial practice on how knowledge can be effectively sourced. This is achieved by realising a research survey, where using the resulting insights KBE practice reaching aerospace engineering offices shall be more efficiently delivered through fast and accurate knowledge extraction and encoding into usable methods and tools.

This paper is organised as follows. First, the design and methodology followed in this paper are described in Section 2. This is followed in Section 3 by the analysis of the research activities carried out in a large aerospace organisation (Airbus Group) which highlights the need for further investigation to increase the efficiency of the knowledge sourcing practices leading to more efficient KBE methods and tools. Section 4 evaluates previous research work related to KBE, categorising KBE applications present in the literature and underlining the KBE research challenges associated to the knowledge sourcing process. In Section 5, relevant KBE papers are evaluated using two instruments: literature classification and analysis, and expert assessment. After that, in Section 6 concluding remarks are given followed by the discussion of the research challenges and opportunities identified. Finally, a summary of the work realised in this research is briefly described in Section 7.

2. Research design and methodology

The ultimate objective of this research is to calibrate the perceived needs for improved knowledge sourcing identified by the researchers. The scope of the research is limited to the context of engineering design. More precisely, this research is focused on the need for sourcing knowledge that can be exploited through engineering design automation systems (often referred in the literature as knowledge-based engineering systems). Given the objective and the scope of this survey, the key research question was articulated and as follows:

2.1. What are the technical gaps and opportunities to effectively source engineering knowledge for KBE development?

The design of the research emerged from industrial EKM and KBE practice. However, further systematic validation of the industrial practice insights was identified as an instrument to substantiate the existence of the perceived research gap. A key element to perform such assessment consisted on a survey of industrial and academic literature related to the research. However, this approach was also reinforced by expert assessment. The steps followed in this research are briefly described as follows:

2.1.1. Industrial motivation and research problem statement

In this part of the research, insights on the industrial implications of knowledge sourcing are drawn from the experience gained in Airbus Group Innovations. The outcome of this exercise is reported in Section 3.

2.1.2. Development of the survey criteria

In order to structure the survey, the researchers made use of recently reported research on KBE technology challenges to articulate the scope of the literature survey on knowledge sourcing. An outcome of this research step is the identification of 4 functionalities of KBE systems that can be used as criteria for the survey. Section 4 reports on this aspect of the research.

2.1.3. Literature analysis and classification

The scope of the review included two types of research articles and reports. On one hand, articles describing traditional KBE applications. This subset includes research reports focused on the automation of repetitive tasks which also supports the management of the knowledge outside the application. This imposed constraint was used as the criteria for the authors to consider that the improvement of knowledge sourcing was part of the aim of the research reported in the papers. Refs. [10,13,14,23,24,26,27,31,32,34–38,7,48,21,49,5,50,51,53,29,54–56,25,57,39,58,30,59–85,11,86] fall into this segment of the research work surveyed. Another set of research articles was identified in references [9–14]. This set of articles features the use of Artificial Intelligence techniques as part of its implementation that contributes to the sourcing of engineering knowledge. The combined set of relevant literature sources includes 55 research articles reporting KBE implementations relevant for the scope of this research.

To reach this subset of relevant articles, extensive filtering and searching was required. The keywords used to identify the relevant literature included "knowledge-based engineering and engineering design" and "artificial intelligence and knowledge-based engineering". In order to reduce the number of papers and facilitate the finding of the significant ones, multiple searches were carried out using combinations of the keywords. For instance, when searching in Science Direct for "artificial intelligence + knowledge-based engineering + engineering design" more than 32 000 articles results appear on the screen. Thus it became apparent the need of filtering the files browsed. As a general rule applied in this work, the content type was constrained to articles from journals and conferences. For this case in particular, the number of papers obtained were considerably reduced when excluding from the search some journals titles and study topics like "Artificial intelligence in medicine" and "interface" respectively.

When manually screening the results, it becomes apparent that the results are ordered by their relevance with the keywords used in the search. Therefore, it was common that in most of the cases only the first three pages (600 articles) were containing relevant papers. After going through the first 600 articles on the search list, abstracts of those articles with titles concerning with the search were revised and only those articles with relevant abstracts were stored and classified in a comparison matrix. In this context, most of the relevant papers were found using Scopus, Science Direct and Springer Link external databases [15–17]. More than 70 papers have been identified as important for this work with around 55 articles (KBE applications) of vital importance.

The classification of the research articles passing the various filters was realised using a set of functional roles which encompass aspects of KBE and knowledge sourcing) described in the Section 4. Moreover, the outcome of the literature classification using the functional roles is documented in Section 5.