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KNOWLEDGE TECHNOLOGIES IN ENGINEERING DESIGN

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1. Introduction

Knowledge Technologies are used to capture and organise knowledge, to store and retrieve it, to keep it up to date, to disseminate it and to reuse it in different contexts. Knowledge Technologies provide solutions that enable companies to turn individual knowledge into manageable assets. They are vital to the success of companies seeking a competitive advantage in a knowledge-based economy. This article intends to give a survey of the application of knowledge technologies in engineering design.
The article gives a short outline of knowledge management and knowledge technologies. The goal is to have a closer look at knowledge related research in engineering design. The article adopts a common framework for knowledge technologies. This framework is a basis to assess recent research contributions. The conclusion suggests areas for future research.

2. Knowledge and Knowledge Management

We define knowledge pragmatically as information sufficiently interpreted to enable action. Information might be defined as ‘raw’ data that has been structured and represented for the human senses.
Knowledge management aims to make an organisation’s knowledge – information and its corresponding contextual interpretation – available to increase business performance. Knowledge management is the sum of all the processes that govern the identification, creation, capture, dissemination, maintenance and utilisation of knowledge. Knowledge management is a blockbuster trend of today’s business: The amount of information available within and across organisations is increasing. Other trends are a shortage of skilled labour, shortened product life cycles, further rise of global commerce, and the Internet. Using information, interpreting it and applying it to business processes is at the core of adding value to products and services.
Managers – and designers – are confronted with an enormous amount of information. Reaching their decision they can be sure of but one thing: they have not taken everything in account properly. Elements of knowledge management can support them – if only to anticipate surprise.
Knowledge technologies propose one way to efficiently handle information overload. They support users to solve complex problems. These problems can not be solved without domain specific knowledge. Knowledge-based systems comprise knowledge bases and reasoning or problem solving capacities.
Technology can play an important role in knowledge management. It is important though to understand that knowledge management is not merely a technology or IT issue. Knowledge management relies on a strong foundation of enablers: One of them is technology. Others are strategy, leadership, culture, and organisation.

3. Design Knowledge and Knowledge Management in Engineering Design

Design knowledge stems from various design-related tasks. It is again applied performing these tasks. Knowledge-based systems in engineering design capture product and process information. Knowledge representations are product and system models, design theories, methodologies, and best practices and engineering expertise [Chapman & Pinfold 1999].

The design process makes use of different classes of knowledge. The acquisition, structuring, retrieval and management of large amounts of knowledge is crucial to support design decisions [Ullmann & D'Ambrosio 1995]. Thus knowledge management in engineering design is concerned with theories, methods, and systems for acquisition, representation, and effective management of design knowledge. This results in databases, information management approaches, the organisation of design processes, design methods and supportive tools.

Szykman et al. suggest the term design repository as "an intelligent knowledge-based design artefact modelling system used to facilitate the representation, capture, sharing, and reuse of corporate design knowledge" [Szykman et al. 2000]. A design repository holds a more complete design representation than a design database. It may include formal data as well as informal models, structured and unstructured text, mathematical simulation models and more. Search and retrieval possibilities make use of more sophisticated methods like mapping between physical and functional decompositions, or search for entities that satisfy required functions.

4. A Knowledge Management Framework

To assess knowledge management solutions we use a framework that consists of six basic challenges of knowledge management: to acquire, to model, to reuse, to retrieve, to publish, and to maintain knowledge. This model has been proposed by the AKT consortium that brings together academics from five British universities: Southampton, Edinburgh, Aberdeen, Sheffield and The Open University [AKT 2001].

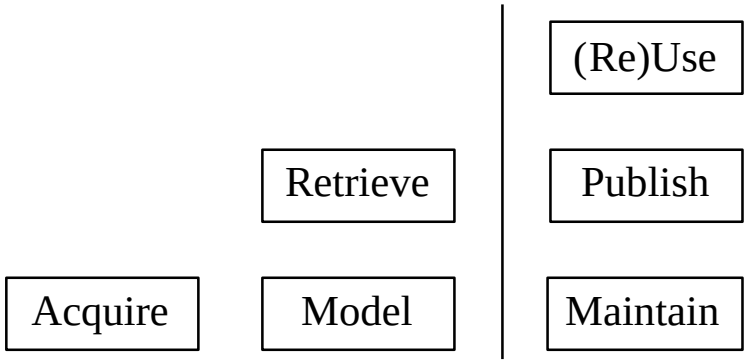

Figure 1. Six Challenges of Knowledge Management

Knowledge acquisition technologies – to get hold of the information that is around – are widely available. It is still a matter of research how to acquire knowledge from unstructured sources like natural language. Acquiring knowledge from different media or from sketches is especially interesting for applications in engineering design.

Modelling establishes a framework to structure knowledge for use, retrieval and publishing purposes. Research focuses on domain related models. In engineering design such models reflect best practices, argumentation, or design rationales.

Building knowledge bases is expensive. To re-use them in a different context than they were created from can increase the return on the investment. Re-using design elements or parts is already common practice in engineering design. Re-using ontologies and problem-solving methods could lead to adapt existing knowledge bases for use in new contexts – e.g. using design knowledge bases in manufacturing or maintenance knowledge bases in design. The re-use of user profiles or navigation strategies etc. opens more interesting perspectives.

Knowledge retrieved from a knowledge base has to be accurate and exhausting, even when knowledge bases get very large, when they are distributed, or when they are quickly changing. It is still a challenge to retrieve knowledge from different sources – e.g. text and unstructured sources.
Publishing knowledge has to present a certain selection of knowledge, in a specific form, at a time specified to the person who requests or needs it. The issue is not to automate the dissemination of knowledge. More interesting and promising are the construction of personalised presentations as a combination of visualisations or summaries in natural language. Agent technology, natural language generation, and multimedia authoring are important supporting technologies.
Maintenance of knowledge bases is a very important issue. When a knowledge-based system acquires new knowledge it must keep itself consistent. A system must be able to evaluate, update, or debug its content. Some content dates quickly. Other knowledge has a considerable longevity. ”Forgetting” knowledge when it is obsolete is a special challenge here.

5. Research on Knowledge Management in Engineering Design

We wanted to find out to what extent researchers in engineering design are concerned with knowledge management and knowledge technologies. We investigated the proceedings of the 1999 and 2001 conferences [Lindemann et al. 1999, Culley et al. 2001].

5.1 ICED’99

In ICED’99 the topic Knowledge Handling covers 17 oral presentations and 12 posters. The former are sorted into subtopics: Acquisition (5 papers), Modelling (4), Knowledge Bases and Fuzzy Logic (4), and Knowledge Management (4).

Table 1. ICED’99 Papers (ICED’99 Categories)

Topic/Subtopic	Number of Contributions
Knowledge Handling	12 *)
Acquisition	5
Modelling	4
Knowledge Bases, Fuzzy Logic	4
Knowledge Management	4
*) Posters were not classified into subsections	

5.2 ICED’01

ICED’01 uses a different approach to classify the knowledge management related contributions. Posters and oral presentations are grouped under four topics.

Table 2. ICED’01 Papers (ICED’01 Categories)

Topic	Number of Contributions
Information Management	8
Knowledge Representation, Knowledge Management	10
Classifications and Taxonomies	6
Design Reuse	8

Information management (8 papers) comprises approaches like solution spaces, dealing with non-structured data, communication, and case-based design. Key issues of knowledge representation and knowledge management (10 papers) are agent technologies, use of domain knowledge, or knowledge abstraction. Classifications and taxonomies (6 papers) are the subjects of lively discussions on a common design language, and product development process ontologies. Design re-use appears as a new heading with 8 papers. ICED’01 contributions focus on documentation, and experience mapping.

5.3 Coverage of the Six Challenges of Knowledge Management

We cross-referenced the contributions of ICED'99 and ICED'01 to the knowledge management framework presented. We classified each paper according to the six "challenges" (acquire, model, (re)use, retrieve, publish, maintain). Of the total of 61 papers 2 could not been classified and 2 fell into two categories.

Most papers deal with the modelling of design engineering knowledge: 19 in 1999 and 20 in 2001. Publishing and maintenance of knowledge are the least covered subjects with one paper each in 1999 and only one paper on publishing in 2001. Papers on acquisition and on retrieval have substantially dropped in numbers from 7 and 5 in 1999 to 3 and 2 in 2001 respectively. While ICED'99 had only 2 papers on knowledge reuse this number went up to 8 in 2001.

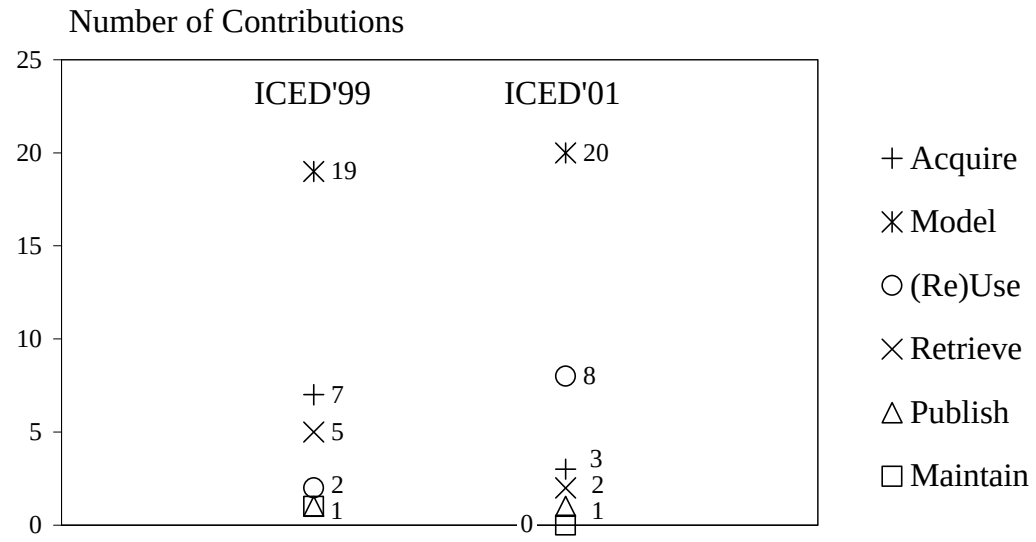

Figure 2. Coverage of the Six Challenges of Knowledge Management (ICED'99 and ICED'01 Papers)

Although the data used is far from being comprehensive, we try to make some tentative comments on the findings. In general the coverage of the six challenges in engineering design is similar to their coverage from research in knowledge technologies.

Acquisition of knowledge has reached a considerable level of maturity in the sense that a number of tools are commercially available. But the drop in contributions on acquisition should not disguise the fact that there are still major challenges, such as to capture tacit design knowledge.

Modelling stays ahead of all contributions. This is not surprising since modelling is probably the second most important activity designing knowledge-based systems apart from knowledge acquisition.

The rising number of papers on reuse mirror a trend found in knowledge engineering. It is important to establish a broad understanding of reuse as e.g. Smith & Duffy do: "We currently consider 're-use' to reflect the utilisation of any knowledge gained from a design activity and not just past designs of artefacts" [Smith & Duffy 2001].

The drop in papers on knowledge retrieval can be seen as paralleling the drop in papers on knowledge acquisition. However commercially knowledge retrieval technology shows no outperforming results.

Knowledge publishing is generally a new field of research and application. This might explain the small number of contributions to ICED'99 and ICED'01.

Little work is found on the maintenance of knowledge-based systems. This is true for engineering design as well as for other research in knowledge-based systems.

6. Suggestions for Further Research

Further research on knowledge-based systems in engineering design will have to take account of current developments in knowledge technologies, and of industry needs.

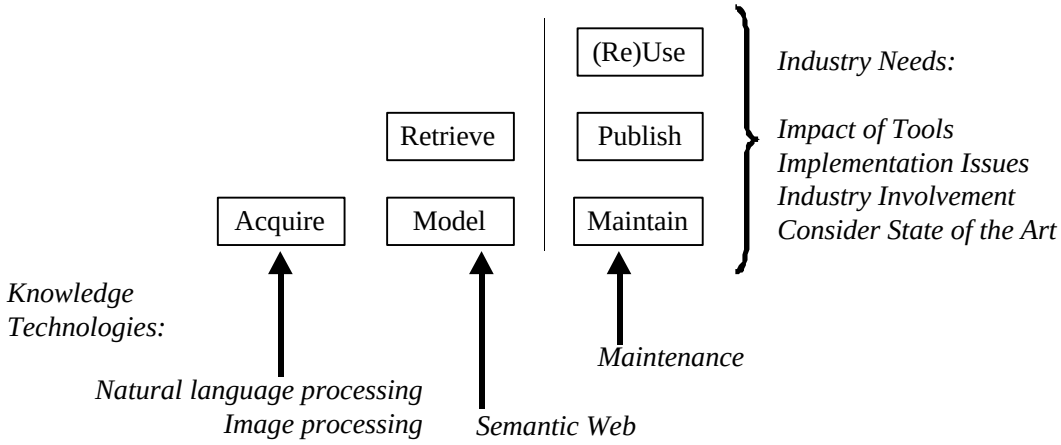

Figure 3. Development in Knowledge Technologies and Industry Needs

6.1 Current Developments in Knowledge Technologies

Natural language processing is a fast growing field of research. This technology is soon able to process written and even spoken text automatically. However, it still remains difficult to process images in a similar way. Indexing and tagging images using knowledge technology is a major issue in (semi-) automatic knowledge acquisition.

The most important technology trend today is the development of the semantic web [Berners-Lee 1998]. Large-scale, general-purpose ontologies find increasing use in science and business.

The issue of maintenance will be confronted in knowledge technologies research. Keeping track of knowledge, recognising outdated content and eventually discarding of obsolete parts of a knowledge-based system has to be addressed.

6.2 Industry Needs

According to a UK study [Culley et al. 1999] support for information and knowledge handling is the most important requirement of industry. It is followed by “tools for the new environments (global, distributed, supply chain), understanding of customer requirements, support for design innovation, good people, ‘intuitive’ tools and systems, and access to tools, information, best practice.” The study reports a general feeling that there was a lack of methods and procedures to assess the impact of new technologies introduced in industry.

Culley et al. conclude that knowledge and information management is a key issue although it has been attacked from a number of perspectives over the years. They suggest to initiate a multi-disciplinary programme on this subject bringing together researchers from design science, computing science, and cognitive or information science [Culley et al. 1999].

Cantamessa notes ”the relative ‘isolation’ with which authors engaged in the development of new tools appear to work with respect to industry needs, to the current state of the art, and to implementation issues” [Cantamessa 2001]. He encourages industrial involvement in this kind of research projects.

6.3 Possibilities for Future Research

From these findings we tried to develop a tentative list of possible issues for future research:

- Acquisition – (Semi-) automatic indexing and tagging of images is a challenging issue in design knowledge acquisition. Acquiring tacit knowledge of designers is still worth investigation.

- Modelling – Global-purpose ontologies might get used to a large extent e.g. in e-business environments. This could lead to reviewing purpose-built ontologies like STEP, and it could encourage more research in modelling and retrieval.
- Publishing – Personalised content publishing that takes in account the actual needs and interests of an engineer could receive some research interest. The possibilities of customised knowledge publishing to support decision-making in top-level design could be investigated.
- Re-use – The reuse of knowledge-systems should remain an issue of research since it improves the return on investment for academia and industry.
- Maintenance – Updating, debugging and pruning design knowledge repositories is an important issue. Since this is still an area of emerging research in knowledge technologies it might take longer until this issue attracts a significant proportion of research in engineering design.

We consider it important that further investigation in these areas should be carried-out in multi-disciplinary projects including design science, computing science, cognitive or information science, and industrial psychology. Research thus benefits from their relative background knowledge and experience. The projects should involve industry to consider the practical impacts of tools developed.

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