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A case study of how knowledge based engineering tools support experience re-use

Andersson Petter[1], Isaksson Ola[1], Larsson Tobias[2]

Volvo Aero Corporation, PD Process Management Dept
SE-461 81 Trollhättan, Sweden.
Fax: +46 520 98550 Phone: +46 520 94377
petter.andersson@volvo.com

Luleå University of Technology, Functional Product Development, SE-971 87 Luleå, Sweden

Abstract: A manufacturing company's unique intellectual capital is to a large extent built on experience from its own product development and manufacturing processes. Thus, methods and tools to utilize and benefit from this experience in an efficient way have an impact on a company's ability to stay competitive and advance on the global market. Knowledge Based Engineering (KBE) is an engineering methodology to capture engineering knowledge systematically into the design system. Hence, KBE tools are considered to support experience re-use and improve engineering activities. This paper presents the results from a study where the objective was to investigate the support for experience re-use in KBE applications in an aerospace company. A proposed framework is presented to analyze the capturing and use of experience in a company's processes identifying gaps and propose improvements. The study revealed weaknesses in the process steps for experience feedback which can be used to improve KBE applications further.

Keywords: Experience re-use, Engineering design, KBE, Case study

1 Introduction

Experience from a companies product development and manufacturing processes, in combination with knowledge about down stream phases of usage and disposure of the product; offer unique insights that provide a competitive advantage. This knowledge is not accessible for competitors and is often difficult to re-build. However, knowledge is not automatically captured and shared in the organisation [1, 2] and there is a need for knowledge management strategies and systems to support the process [3, 4]. Thus, methods and tools to utilize and benefit from experience have an impact on a company's ability to compete and advance on the global market.

Knowledge Based Engineering (KBE) is an engineering methodology to capture engineering knowledge systematically into the design system [5-7]. Hence, KBE tools are considered to support experience re-use closely related to the design process and is used in a number of companies to improve engineering activities [8-12].

This paper presents the results from a study where the objective was to investigate the support for experience re-use in KBE applications in an aerospace company. Initially a proposed framework is presented based on a data-information-knowledge hierarchy and an experience life-cycle (ELC) process[13].

1.1 Data, Information and Knowledge

In knowledge management literature, a pyramid is often used to illustrate a hierarchy between *data*, *information*, *knowledge* and *wisdom* (DIKW) [14].

In the DIKW hierarchy each category includes the categories that fall below it, as stated by Ackoff [15]. Hence, wisdom is the sum of knowledge, information and data captured in the organisation by its people and supporting system.

According to Rowley [14] the interpretation of the DIKW hierarchy varies and there is no general understanding for the definitions of the categories included in the pyramid. The advisable of using the hierarchy is also questioned in the academia [16].

In this work we focus on the three lower categories of the pyramid, data, information and knowledge. The categories are used to provide a structure for the feedback process from the occurrence of the experience through the cycle where it is analyzed, stored, found and used.

The characteristics of data, information and knowledge used in this work follow the argument of Ahmed and Blessing [17] where the categories are relative to a user perspective;

- Data is fragmented information without context.
- Information is data in context that can be interpreted by the user.
- Knowledge resides within the user and represents the interpretation and understanding of information.

Data, Information and Knowledge are relative terms meaning that what is information for one user can be data to another.

1.2 Life cycle perspective

This work builds on previous work by the author [13] where a life-cycle process describes the phases from the emerging of experience element through capturing, analysing, storing, search & find, access, use and re-use the experience. A modified version of the referenced life-cycle is illustrated in Figure 1. The new version includes the “access” step in step 5 for search and retrieve. The modification has been found to be logical and simplifies the model.

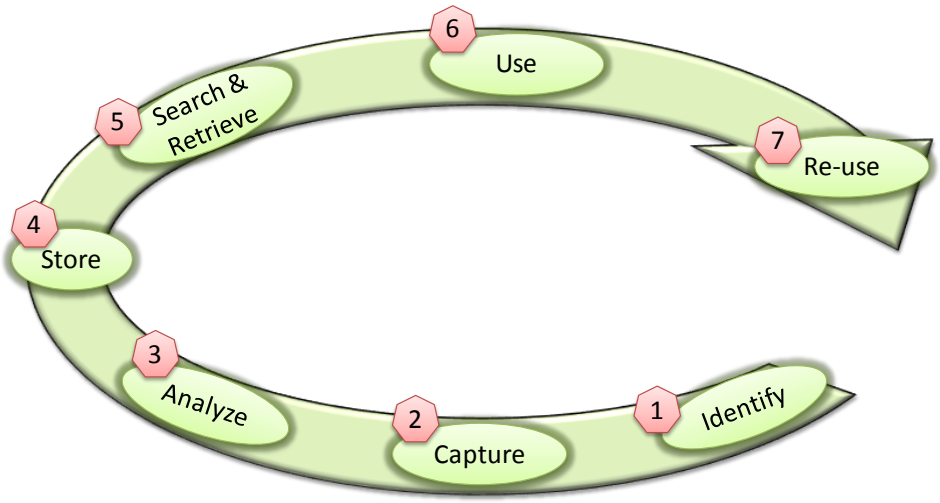

Figure 1 The life-cycle of experience

Here, experience has a broad definition and can be in the form of knowledge (individual or group of people), information (documents, presentations) and data (symbols, fragments of information without context). Below follows a description of the phases in the process for experience feedback.

1. **Identify:** The identification phase denotes the occasion where the governing situation leading to "experience" occur. In practice, this can be a non-conformance that appears in manufacturing due to an ill-defined product definition feature. The "experience" is made only if anticipated as such. If not anticipated as experience it is merely information and data about an instance or incident.
2. **Capture:** In the capturing phase "experience" that is considered/judged as important is captured in some type of media. Most commonly paper document but other media types could by audio or video records.
3. **Analyze:** In the analyze phase a "root cause" analysis of the captured "experience" is made to identify appropriate strategy for re-use and when found necessary, corrective actions to avoid recurrent deviations.
4. **Store**: In the store phase insights from the analysis is recorded in some format and archived. The way that the "experience" is stored is decisive for how the "experience" can be searched for and that appropriate access rights are assigned the information.
5. **Search & retrieve**: In the search and retrieve phase the "experience" is search for and retrieved.
6. **Use**: The use phase denotes the step where the element of experience is used in. Typically reading a document or using some sort of system support.
7. **Re-use**: The re-use phase connects the cycle with the first task, identify (1) in order to close the cycle where the result from the previous step is evaluated. E.g. user feedback to author of instructions or application developer. An important aspect is to also consider the final outcome of the used information. Did the resulting product/component meet the required expectations?

Mapping the capturing and use of experience in a company's processes with the presented experience life-cycle it is possible to analyse gaps and propose improvements using methods and tools in relation to the framework. The DIK categories visualise the elements of experience that is managed in a company. In this work, the relationship between the elements is modelled, from the identification and capturing of the experience throughout the life-cycle to it is re-used.

2 Research approach

Here, a framework is described to facilitate the analysis of how knowledge based engineering tools support experience re-use. In practice, a form is used to analyse the process for experience re-use, recognizing data, information and knowledge for each of the stages in the experience life-cycle and the current status. The data collection has been accomplished by iterative interviews and a survey of company documents. The result enables the engineer to identify and visualize gaps in the current processes in order to improve the process.

The study is explorative and includes *how* and *why* questions which allow a case study strategy following the suggestions by Yin for Case Study Research [18]. The company in the study is a jet engine component manufacturer. The author of this article is an employee at the company studied and has been part in the development of the applications mentioned in the research. Hence action research has been chosen as a strategy to guide the work [19].

3 Framework

The notation of "elements of experience" is introduced to denote *knowledge* (Individuals or group), *information* (documents, presentations) or *data* (symbols, fragments of information without context). The relation between the different categories can be visualized as shown in Figure 2.

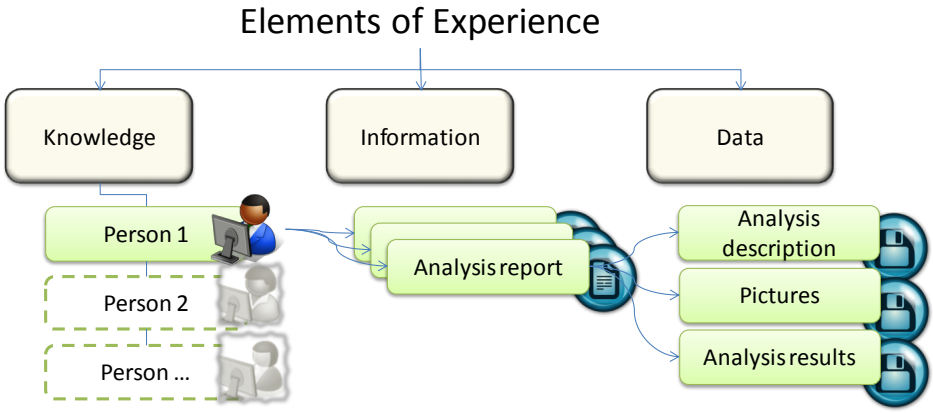

Figure 2 Illustrating a relation between knowledge, information and data.

Again, knowledge, information and data are relative terms and what is considered as data in one situation can be considered information in another. Also, the categories inherit the properties from the lower in the pyramid, i.e. knowledge is data in context that has been interpreted by the engineer.

In this view we see the importance of providing the engineer with the right contextual information that enables the engineer to understand and gain knowledge. Figure 2 illustrates the relation between the engineer, the report and its components (Data). Keeping these relations in mind while following the process for experience feedback we realise (or confirm) the importance of ensuring that the user have the knowledge to interpret the information when it is to be used again. Further, the components of a report are also an essential part that represents a context. Is it possible to find the references in the report? Is there data available to verify the result in the report?

3.1 Experience Life Cycle in a KBE context

In this work we use the KBE lifecycle that has been described by Stokes et al. [20] to provide a KBE context to the activities in the ELC process described earlier. Stokes et al. describes the KBE life cycle by means of six steps; Identify, Justify, Capture, Formalize, Package and Activate.

Table 1 describes the activities from the KBE life cycle mapped into the experience life cycle described earlier.

Table 1 Life cycle to map experience re-use in the KBE blade application

ELC steps	Life cycle steps described in a KBE context.
Identify:	Investigate the business needs and to determine the type of KBE system that might satisfy those needs and justify aims to seek management approval to continue.
Capture:	Collect the domain knowledge and create a product and a design process model.
Analyze:	Carry out root cause analysis to identify appropriate strategy for re-use and when found necessary, corrective actions to avoid recurrent deviations.
Store:	Create a working KBE system using the formal models and activate by distribute and install the KBE application.
Search & Retrieve:	The KBE application is provided in the engineering context, i.e. design environment, encoding CAD system and DP practices.
Use:	Use the KBE application.
Re-use:	The cycle is closed by identifying need for enhancement of the application. This can be done by feedback from the users of the application as well as continuing improvement activities that evaluate the outcome from down stream activities.

3.2 Process improvement

With the framework as a base a process improvement approach is possible to map and identify current processes in order to define corrective actions. This case study represents the first part in process improvement efforts as it presents the current situation and not corrective actions with follow up activities.

4 Industrial case

In the industrial case we apply the framework previous described to investigate a KBE tool and the support for experience re-use in a design organization. The choice of KBE application was made based on the level of maturity of the application and that results from usage of the tool has been previous published in the design research field [9]. This company's KBE environment is closely integrated to the CAD system. Hence issues regarding product modeling (smooth surfaces, geometric tolerances and modeling techniques) are a central part of updating activities.

4.1 Aero-blade application

In engineering design of aerodynamic components, such as turbine blades, design iterations include design of aerodynamic surfaces and mechanical design of the blade itselves. The design covers aerodynamic disciplines and design tools, as well as mechanical design tools for the physical design. A KBE application is well motivated to facilitate iterations between these disciplines. The aero-blade applications support the design engineer by providing rapid generative CAD modeling. Figure 3 show the user interface that provides the designer with options to include specific design tasks and change parameters within a certain design space.

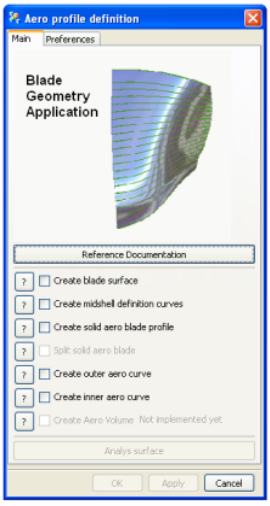

Figure 3 User interface of aero-blade application.

In this KBE application, the blade definition is provided as a list of points defining sections that are swept to form the shape of a blade. The calculation and optimization of the aero profile is made in a separate tool, prior to modeling of the blade. Additional support for mid-shell definition is also incorporated in the aero-blade application as it names surfaces and defines key edges.

4.2 Mapping the case into the framework

Applying the framework described earlier for KBE application we attain the following results presented in Table 2. Each step where evaluated from a re-use perspective to find weaknesses and propose improvement activities.

Table 2 Instance of the KBE blade application in the framework

ELC steps	Life cycle step description
Identify:	The aero-blade definition is a time consuming CAD task that involves several steps and depends on iterations between the disciplines of aero-thermal simulation, CAD modelling and manufacturing preparation. This has been found to be a bottle-neck in engineering design and automation of this activity was identified as great potential for reducing labour intensive work in product development (PD).
Capture:	Knowledge from disciplines where captured by KBE engineers following the MOKA methodology using interviews and ICARE forms.
Analyze:	The collected material was analysed and iterated with specialists from aero-thermal simulation, CAD modelling and manufacturing preparation. Analysis of captured information revealed; • No standardized geometrical representation format caused corrupt data files, ill defined geometries, inconsistencies and problem in sub-sequent geometrical operations. • Tedious and frequent occupation of CAD modellers to assist in modelling and translating geometries between the disciplines (aero. Mech. and Manufacturing) • Manufacturing of geometries optimized from aerodynamic, and sometimes mechanical objectives, became difficult, expensive or even impossible to manufacture. • There were (AS IS) several co-existing ways to model aero-blade geometry in CAD, often resulting in bad geometry definitions downstream in the CAD process. Leading to corrupt CAD-data files. In addition there were difficulties for other engineers to understand the CAD model structure and continue the work on some one else's CAD model. • Time consuming and tedious work that not only requires CAD design resource time to do the CAD work is also a bottle neck because of the limited number of CAD designers available when needed.

	• Aero-blade geometry not optimized for manufacturing where discovered late in the design phase, leading to re-design with non optimized solutions. A KBE solution were confirmed to be a good solution that re-use the captured engineering knowledge and created uniform CAD models cross company projects that comply with CAD standard methodology, Aero-thermo performance requirements and robust design for manufacturing.
Store:	The captured knowledge was stored in the organisation by the development of a KBE aero-blade application that was integrated in the CAD design engineering environment. However, the application was not made available for all users and is not part of the standard KBE package provided for design engineers. The new routines for definition of the aero profiles are stored as part of the company's standard documentation for definition of aero profile data is adapted to meet the format of the KBE system. Design Practices (DP) for generating aero profile geometry is updated to reference the KBE-application to create the CAD definition.
Search & Retrieve:	The engineer is directed to search for and follow the directives in the design practices in which the aero-blade application is referenced. The Aero-blade application is not available in the CAD design engineering environment and the designer has to request for access to be able to install the application. This limit the usage with an increased number of deviations derived from ill defined CAD definition.
Use:	The application is used by design engineers in a CAD design engineering environment. The application is found to be easy to use but not always accomplishing the desired result, causing requests for update of the application. Generally it has been found to be an improvement when compared with previous way of working.
Re-use:	Enhancement requests of the application can be sent to the department responsible for KBE support. The produced geometry is validated in the same review process as the complete CAD model and problem found here is sent back to the user of the application (CAD engineer). Such problem report provide a mechanism to closes the life cycle loop as it has been identified as an experience and captured as a deviation report to be analyzed.

4.3 Identified weaknesses

A weakness was identified that related to the steps of "store" and "Search & Retrieve". It was found that the aero-blade application was not fully implemented in the CAD environment leading to limitations in accessing the application.

Although there where no explicit routines for continues improvements, a number of enhancement requests from different stakeholders in the design process have resulted in new versions of the KBE application.

5 Conclusion & discussion

The aim of this case study was to investigate how KBE tools in an industrial implementation support the re-use of experience in the organisation. A framework for experience re-use that built on previous research was described and set into the context of KBE applications. Each step in the life cycle considers key aspects from a re-use standpoint.

Using the Experience Life Cycle framework on an existing KBE application, it was shown that the KBE application clearly met the objectives within *Identify*, *Capture* and *Analyze*. The phases for *store* as well as *Search & Retrieve* were not as clearly facilitated whereas the *Use* and *Re-Use* was supported but with no explicit routines for continues improvements.

Other KBE applications in the company is likely to have similar weaknesses as the one studied and the result from this work is expected to have an impact on other ongoing improvement efforts within KBE development.

It is clear that the use of this framework does not cover all possibilities for experience re-use. However, the framework provides a tool to systematically identify weaknesses which can be used to improve the application further.

It is believed that a continuing use of the framework to evaluate other engineering tools will improve the understanding of what is important and relevant to question in each phase of the experience life cycle.

A concern that where raised during the study was that experience is in some way perishable and the use of “old” experience instead of “fresh”, more resent findings can be negative for a company’s strive to compete with new innovative solutions. With that said, it is obvious that the experience life-cycle needs to be a continuo’s process that is regularly updated.

The ability to provide the engineer with “live” experience data from production and other follow-up activities could be the next step of KBE development.

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