A CASE STUDY OF HOW KNOWLEDGE BASED ENGINEERING TOOLS SUPPORT EXPERIENCE RE-USE

Andersson Petter[1,a], **Larsson C. Tobias**[2] **and Isaksson Ola**[1,b]

[1] *Dept. of PD Process Management, Volvo Aero Corporation, SE-461 81 Trollhättan, Sweden*
Email: [a]*petter.andersson@volvo.com,* [b]*ola.isaksson@volvo.com*
[2] *Division of Functional Product Development, Luleå University of Technology, Luleå, Sweden*
Email: tobias.c.larsson@ltu.se

A manufacturing company's unique intellectual capital is to a large extent built on experience from its own product development and manufacturing processes. Thus, efficient methods and tools to utilize and benefit from this experience 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 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 categorization and an experience life cycle (ELC) process [13].

1.1. Research approach

A framework is described to analyse 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

Research into Design — Supporting Sustainable Product Development. *Edited by* Amaresh Chakrabarti
 :: *Published by* Research Publishing
ISBN: 978-981-08-7721-7

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 [14]. 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 [15].

1.2. Data, Information and Knowledge

Structuring the "elements of experience" into categories of knowledge, information and data is one way to decompose the multifaceted task of experience feedback.

In knowledge management literature, a pyramid is often used to illustrate a hierarchy between *data*, *information*, *knowledge* and *wisdom* (DIKW) [16].

In the DIKW hierarchy each category includes the categories that fall below it, as stated by Ackoff [17]. According to Ahmed and Blessing [18], data, information and knowledge are relative concepts, where information can be data for some users and knowledge for others. The interpretation of the DIKW hierarchy varies and there is no general understanding for the definitions of the categories included in the pyramid [16]. The advisable of using the hierarchy is also questioned in the academia [19].

However, this work focuses on the three lower categories; data, information and knowledge. The categories are used to describe the different aspects of experience in the feedback process from the occurrence of the experience through the cycle where it is analyzed, stored, found and used.

1.3. Life cycle perspective

Another way to decompose the multifaceted task of experience re-use is to view the feedback process as an Experience Life Cycle (ELC). Here, typical activities in the feedback process are identified and modelled. The work presented in this paper builds on previous research by the author [13] where the feedback process is described by the activities; *identify*, *capture*, *analyse*, *store*, *search & find*, *access*, *use* and *re-use*. A modified version of the referenced ELC is illustrated in Figure 1. The new version includes the "Access" step into the "Search & retrieve" step. The modification has been found logical and simplifies the model.

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 typical activities in the process for experience feedback.

- **Identify:** The identification step denotes the occasion where the governing situation leading to "experience" occur. In practice, this can be a non-conformance that appears in manufacturing due

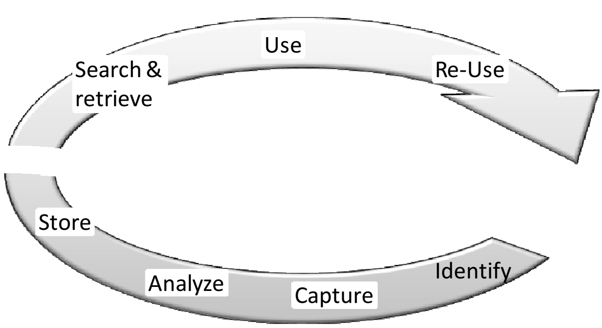

Figure 1. The life cycle of experience.

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.

- **Capture:** In the capturing step "experience" that is considered/judged as important is captured in some type of media. Most commonly are paper documents but other media types could be audio or video records.
- **Analyze:** In the analyze step 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.
- **Store**: In the store step 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.
- **Search & retrieve**: In the search and retrieve step the "experience" is search for and retrieved.
- **Use**: The use step denotes the step where the element of experience is used in. Typically reading a document or using some sort of system support.
- **Re-use**: The re-use step 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?

By adopting the experience life cycle on 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.

2. FRAMEWORK

The framework decomposes a multifaceted task by identifying typical activities in the feedback process and describing how the "elements of experience" is managed throughout the process. The notation of "elements of experience" is introduced to denote knowledge (by individuals or a group), information (documents, presentations) or data (symbols, fragments of information without context). Figure 2 illustrates the relationship between the different categories.

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

Knowledge, information and data are relative terms and what is considered as data in one situation can be considered information in another.

The illustration highlights the importance of providing the engineer with the right contextual information that enables him to gain knowledge. Keeping the 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

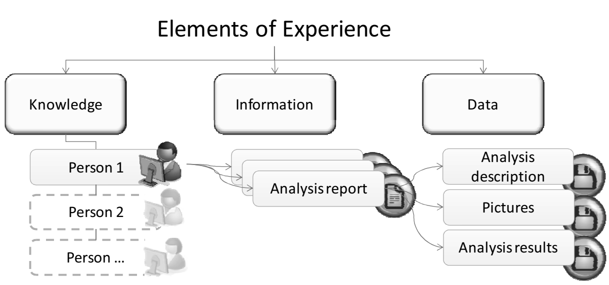

Figure 2. Illustrating a relation between knowledge, information and data.

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.

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?

2.1. Experience Life Cycle in a KBE context

The KBE lifecycle that has been described by Stokes *et al*. [20] provides a KBE context to the activities in the ELC process described earlier. The KBE life cycle is described in 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.

3. INDUSTRIAL CASE

In the industrial case we adopt the framework previous described to investigate how a KBE tool support experience re-use in the product development work. 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 the product definitions updating activities.

3.1. Aero-blade application

The blade design is a multidisciplinary engineering design activity involving optimization within the disciplines of aero-thermal, mechanical and manufacturing. 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.

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. Parts of 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.

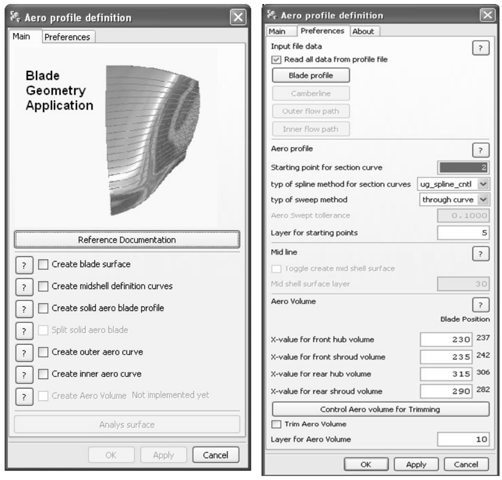

Figure 3. User interface of aero-blade application.

3.2. Adopting the framework

Adopting the framework described earlier for KBE application we obtain the following results presented in Table 2. Each step was evaluated from a re-use perspective to identify weaknesses.

3.3. Identified weaknesses

Weaknesses were identified relating to the activities to *"Store"* as well as *"Search & Retrieve"*. It was found that the aero-blade application was not fully implemented (stored) in the CAD environment leading to limitations in accessing (Search & Retrieve) the application. 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.

Although there were no explicit routines for continuous improvements, a number of enhancement requests from different stakeholders in the design process have resulted in new versions of the KBE application. However, the occasions when the KBE tool failed to accomplish requested results did not always lead to a request for an update of the tool, instead informal routines were adopted to accomplish the design task and considered best practice.

4. 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. The study represents the first part in an improvement effort and presents the current situation and not corrective actions.

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 described experience life cycle considers key aspects from a re-use perspective.

By adopting the framework on an existing KBE application, it was shown that the KBE application did not meet the objectives within the activities *"store"* and *"Search & Retrieve"*. The activities to *"Use"* and "*Re-Use"* was supported but with no explicit routines to enforce continuous 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 the company's KBE development.

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 was 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 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 was 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 was updated to reference the KBE-application when creating a 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.

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 systematic use of the framework to evaluate other engineering tools will improve the understanding of what is important and relevant to question in terms of enabling experience feedback.

A concern that were 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. Here, the ability of the KBE solution to adopt and support new methods is essential.

The ability to provide the engineer with “live” experience data from production and other follow-up activities was also raised as an interesting area where KBE tools could be more supportive in the future.

ACKNOWLEDGMENTS

I am grateful to VINNOVA and Volvo Aero for the financial support through the MERA programme. I thank my colleagues at both Volvo Aero and Luleå University of Technology that have supported me in my work and giving me the opportunity to act in both an industrial and academic environment.

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