A Methodology for the Elicitation of Redesign Knowledge

Hatem AHRIZ Inés ARANA
The Robert Gordon University, School of Computing,
Aberdeen, AB25 1HG, UK

Abstract. We present MADAM, a methodology which allows the elicitation, capture, analysis and management of redesign knowledge. This area is characterised by the high reusability of problem solutions and is represented using three views: physical, functional and process. The methodology supports the analysis of the knowledge elicited and, therefore, the inconsistencies are detected. In addition, the knowledge is normalised so unnecessary (subsumed) parts and technical solutions can be removed with the aid of the expert. MADAM thus contributes towards better and faster redesign.

1. Introduction

Design is a very important stage in the manufacturing of a product. Redesign is a type of design where the aim is to produce a new variant of a product family in order to satisfy a slightly different specification. The same expertise is used by the designers to produce product variants. Hence, it is an area that lends itself to knowledge reuse. In this paper, we report on our experience in acquiring redesign knowledge using MAKUR [1], a methodology, which supports engineering redesign. It consists of three tools:

- Design Analysis Methodology (MADAM) to elicit, and analyse knowledge.
- Design Description Language (MADD) to represent the knowledge analysed above.
- Design Advisory System (MADAS): an interactive problem-solving tool that provides particular design solutions for a product, given a set of requirements.

This paper concentrates on MAKUR's Design Analysis Methodology (MADAM).

2. Redesign

Redesign is a very time-consuming task to which companies devote lots of resources. For example, oil companies require the design of thousands of pipe supports, which are used in order to restrain the pipes running along offshore platforms (existing steel). When designing a pipe support, it is important to determine where the existing steel is located, whether there are other supports nearby or not, pipe loads and stresses and whether there is anything on the way that may make the support difficult to attach. The designer also needs to consider the client's preferences and policies when several alternatives are available. Figure 1 (a) illustrates a simplified example of a pipe requiring support where the closest existing steel runs vertically and to the west of the pipe. Figure 1 (b) shows the solution to this problem using a frame, pipe shoes and restraints. For details of pipe support redesign we refer the reader to [2].

3. Elicitation of Redesign Knowledge

Designers look at products from different perspectives: physical, functional and process. Although other knowledge elicitation and representation methodologies were considered (e.g., Brown's [5], STEP [6, 7] and CommonKADS [8]), these were rejected because they either provided little adaptation to redesign problems, were too costly to apply or did not elicit all the knowledge required. The three-views model that MADAM aims to build is as follows (Figure 2):

- Physical model: represents the product in terms of the parts it is composed of and their design features. Figure 1.b shows a pipe support composed of a frame, a pipe shoe and a couple of restraints.
- Functional model: describes the various functions that a product satisfies and the technical solutions that implement a function. The design features used in a technical solution relate this model with the physical one. For example, the pipe support in figure 1.b fulfils a "guide and rest" function.
- Process model: describes the tasks which need to be carried out in order to obtain a design and the methods which can be used in order to perform a task.

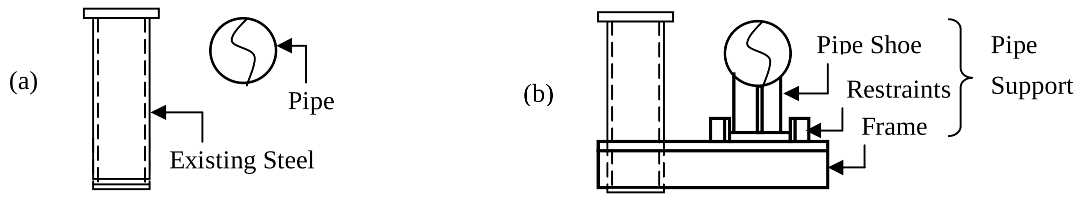

Figure 1: (a) Pipe support environment, (b) Pipe support built in the environment.

All the model entities are described in terms of parameters and their domains. Constraints are used to express the relationships between parameters. In order to produce the design of a particular product, the designer would select the model entities from one or more model views.

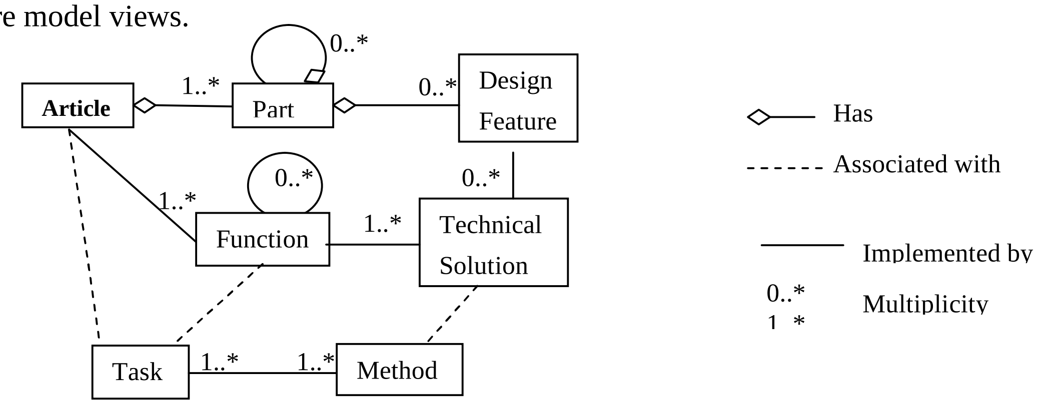

Figure 2: The three model views (from top to bottom): Physical, Functional and Process model.

MADAM (figure 3) first studies the design of a product family in order to gain a general understanding of the product and its design. The application of this phase results in a set of design entities (e.g. functions, parts). Next, the relationships between these entities are identified by looking at the design and its process in more detail. Hence, the knowledge elicitation starts with a top-down approach that extracts the main entities in the domain (analysis) and is followed by a bottom-up approach where the relationships between the entities are elicited (synthesis).

The result of applying MADAM is a three-view model (trees) representing the company's "know how" for the redesign of a particular product family. The three-view product model is represented using a Graphic Editor (GE) which allows the knowledge engineer and designers to browse through this model, and insures the structural consistency of that model (e.g., insure that each function is related to at least one technical solution).

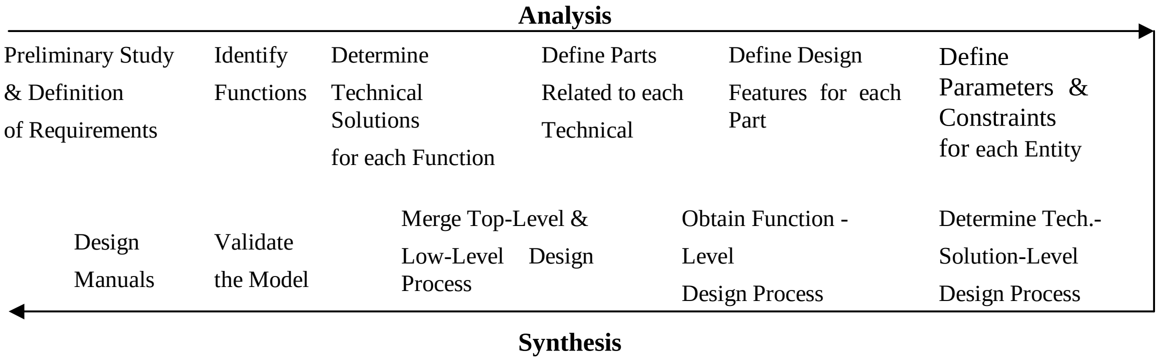

Figure 3: Major steps in applying the MADAM.

In addition to structure checking, the model is analysed to ensure its consistency [7]. The GE uses the constraints associated with the entities in model for checking its validity. The core of the validation tools is a constraint satisfaction engine [4], which ensures that all the model alternatives offered are feasible (i.e. there is at least one valid design solution which uses that alternative). The GE is able to find various types of anomalies in the model (e.g. incoherence, partial conflict, incompatible entities) and assists the knowledge engineer in refining the existing knowledge or eliciting new knowledge. For example, an inconsistency is detected when the parameter pipe1.diameter can take values in [10mm..2000 mm], and there is a constraint pipe1.diameter > 1500, the GE suggests that the domain of values may be reduced to [1501mm..2000 mm]. This suggestion is passed onto the knowledge engineer for approval.. For a complete discussion of model validation in MAKUR we refer the reader to [3]. The methodology uses a variety of knowledge elicitation methods [9]:

- Unstructured interviews are used to gain an initial understanding of the problem.
- Structured interviewsare used to obtain more detailed knowledge which lends itself to structuring and analysis.
- Protocol analysis, where the expert's problem-solving is studied. The designer/engineer is recorded and the tape is then used to extract the general design process which he follows.
- The role shift approach, where the knowledge engineer takes the role of the expert, and the latter validates the knowledge acquired. For example, in one instance, a designer stated that an article had five functions and any combination of these (i.e. 32 functions in total). But when the knowledge engineer looked at hundreds of design drawings, only 13 functions were identified.

- Watching the designer while performing his job: some designers recognise that they may contradict themselves during interviews! Thus the importance of this technique.

The knowledge elicitation process used a variety of sources:

- Discussions with various experts at different levels of the company's hierarchy. The aim was to gain an overall understanding of how the different departments co-operate in the realisation of the article. The methodology, then, focused on discussions with one designer, given that each designer in the company has his own designing style and that finding a consensus amongst all designers is difficult, unless the company is very prescriptive in the way in which designs are realised. The lack of consensus between designers may be the reason why a company's design process is not documented.
- Company documentation: standards and regulations, catalogues of components.
- Design drawings: they constitute a mine of information and can provide the knowledge engineer with many issues to discuss with the designer.

MADAM offers the ability to capture various sorts of knowledge:

- Type-subtype knowledge: since we have observed that designers use this kind of knowledge. Hence, there are two types of hierarchies: (a) Type/subtype hierarchy: For example, "Welded Shoe" is a type of "Shoe". (b) Part/subpart hierarchy: This is a decomposition of the article into parts and design features. The use of such typing enables the inheritance of parameters and constraints from types, thus avoiding redundancy, facilitating reuse and ensuring consistency.
- Default Values: Designers often use default parameter values wherever possible, since this encourages standardisation.
- Optimisation criteria: Designers use a driver (e.g., cost, ease of installation, manufacturing time) in order to select a design solution.
- Prioritised design options: Designers prioritise design solutions. The most desirable technical solution is the option that the designer would try first. For example, an inverted goal post can be the frame default option, and only if this option is not appropriate (e.g. a constraint is violated) that another alternative is tried.
- The various constraints between the model entities are categorised as follows: (i) level of desirability: from desirable to compulsory constraints; (ii) scope: from generic constraints which apply to a type and all its sub-types to local constraints which only apply to a particular entity.

4. Results

The MAKUR knowledge acquisition methodology has been used in various testcases. The following benefits have been reported:

- Reduced variance (standardisation) in the various technical solutions since the methodology encourages the analysis and normalisation of knowledge.
- Prioritisation of these solutions by considering various criteria (e.g., cost, ease of installation, company policies) so that given a set of requirements, different designers will reach the same solution.
- Documentation and retention of the design process. Thus, redesign expertise can be shared amongst designers and is available to novices.

5. Conclusions

Redesign problems are characterised by a well understood domain and the high reusability of their solutions. Hence, it is a very appropriate area for the construction of advisory tools which can help reduce the problem solving time. A first step in the construction of such a system is the development of a methodology for the acquisition (and analysis) of redesign knowledge, so that it can be used in a support system. This is a key issue, since the quality of an advisory system is highly dependent on the knowledge it uses. We have presented MADAM, an analysis methodology for the redesign of product families. It is a two-step task where: (i) the design of a product is first analysed in order to gain a general understanding of the design; (ii) the relationships between entities are identified. MADAM is part of MAKUR, a methodology for the development of redesign support systems which contributes towards a better and faster redesign of product families.

References

[1] Arana, I., Ahriz, H., Fothergill, P. Redesign Knowledge Analysis, Representation and Reuse. *In Industrial Knowledge Management A Micro-level Approach*, Roy, R., (Ed.), Springer-Verlag, 139-146, 2000.

[2] Arana, I., Ahriz, H., Fothergill, P. Improving redesign support. *In Proceedings of the Fifth World Conference on Integrated Design and Process Technology (IDPT'2000),* Dallas, TX, 2000, 8 pages (CDRom).

[3] Arana, I., Ahriz, H., Verification of Redesign Models: A CSP Approach. In the Proceedings of the Thirteenth International Conference on Engineering Design, ICED'01 Glasgow, August 21-23, pp 283-290, 2001.

[4] Barták, R. Constraint Programming: In pursuit of the Holy Grail. In *Proceedings of WDS99 (invited lecture),* Prague, June 1999.

[5] Brown, D.C., Chandrasekaran, B., Design Problem Solving: Knowledge Structures and Control Strategies. *Morgan Kaufmann*. 1989.

[6] Knutilla, A., Schlenoff, C., Ray, S., et al, NISTIR 6160, *National Institute of Standards and Technology*, Gaithersburgh, MD. 1998,

[7] Owen, J., STEP: an Introduction. *Information Geometers Ltd*. 1993

[8] Preece, A. “Evaluating Verification and Validation Methods in Knowledge Engineering. ” In *Industrial Knowledge Management: A Micro-level Approach*, Springer-Verlag, pp. 91-104, 2000.

[9] Rumbaugh, J., Blaha, M., Premerlani, W. Object Oriented Modelling and Design. *Prentice-Hall*. 1991,

[10] Schreiber, G., Wielinga, B., de Hoog, R., Akkermans, H., CommonKADS: a Comprehensive Methodology for KBS Development. *IEEE Expert* 9, 6, 28-37. 1994.

[11] Schreiber, G., Akkermans, H., Anjewierden, A., de Hoog, R., Shadbolt, N., Van de Velde, W., Wielinga, B. Knowledge Engineering and Management: The CommonKADS Methodology, The MIT Press, 2000.