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DESIGN KNOWLEDGE INDEXING IN RELATIONAL DATABASE

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1. Introduction

During product development designers reuse design knowledge. Solutions or methods that are reused are not sufficient solely. Design rationale (meaning, reasons, arguments, documentation (proofs, specifications), choices, critique, consequences, etc) is necessary for efficient knowledge reuse. Traditional CAE tools don't provide the designers adequate support for knowledge capturing and retrieval in organized and efficient manner. Hence, there is a need to develop software tools to capture, store and reuse knowledge [Ahmed, 2005.]. Especially if it is known that improved information and knowledge management can lead to improved product quality, improved performance and significantly reduced time to market. We want to investigate and understand the characteristics of designer's knowledge retrieval needs in order to propose methods and tools for efficient organization of knowledge capture and retrieval process. The long-term aim of this research is improvement of knowledge management process for concept, embodiment and detail design tasks that are parts of complex and long-lasting product development projects which repeat in cycles of 3-5 years. In other words, the research focus is on knowledge management for adaptive (redesign) tasks. We want to investigate and understand the characteristics of designer's knowledge retrieval needs in order to propose methods and tools for efficient organization of knowledge capture and retrieval process.
The research is carried out in collaboration with a small engineering design project office situated in Zagreb. Their tasks are mainly in embodiment and detail design areas, but they do the projects starting from conceptual phase as well.

2. Background

We are considering the design process as an information process or an information transformation process. Engineers typically spend 20-30% of their time involved in information-based activities, particularly searching and retrieving [Court et al., 1998;. Marsh, 1997.]. Up to 4% of that time is spent to identify where this information is in the first place [Marsh, 1997.]. Therefore, an improved process and better final design can be achieved through the efficient and effective utilisation of information and knowledge resources for engineering design. In order to best utilise this information and knowledge it is necessary to provide effective means for their identification, capture, storage and reuse [Hicks et al., 2002.]. Knowledge is the ability of the individual to understand information and describes the manner in which they handle, apply and use it in a given situation [Court, 1995.]. There are numerous definitions of data, information and knowledge from distinct authors which observe them from different points of view. Hicks et al. [Hicks et al., 2002.] have developed formal definitions for data, information and knowledge together with the description of differences, limitations and relations between them, Figure 1. They consider that whilst each is related there are differences between them, and these differences hold the key to better enabling their effective identification, capture and reuse of these resources.

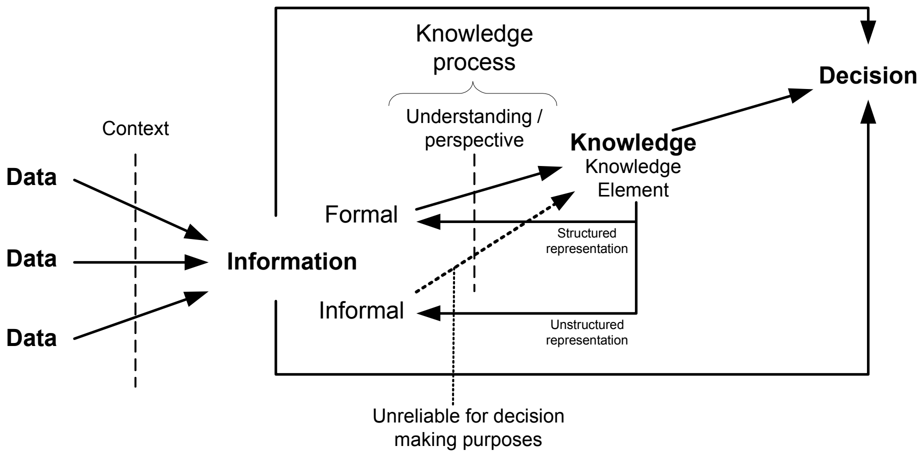

Figure 1. Relationships between data, information, knowledge and decision making [Hicks et al., 2002.]

Many authors distinguish formal (structured) and informal (unstructured) information [Hicks et al., 2002.]. Furthermore, formal information can be verbal, pictorial and textual, and informal information verbal, expression, memory, pictorial and textual. In order to explain relationship between formal and informal information Yang and others propose new information class called semi-formal information [Yang, et al., 2005.]. Such semi-formal information, authors see as design rationale systems. Design rationale draws on the designer's experiences, background knowledge and assumptions and encompasses the reasoning, trade-offs and decisions made throughout the development of the design [Conway et al., 2007]. The challenge many organisations face is how to capture and store valuable informal information in a way that is both simple and efficient, whilst remaining unobtrusive to the designers involved and without inhibiting the design activities. As a response to that challenge there are different researches on capturing, storing and reusing information. Differences and short explanations for proposed methods one can find in [Ishino et al., 2006.]. In general, proposed systems for capturing, storing and reusing information can be divided as follows:

1. those that involve extensive participation by the human designer (disrupting a designer's normal activities)
2. those where system automatically constructs rationale information by using AI techniques, [Myers et al., 2000; Ishino et al., 2006]. These automated systems for capturing, storing and reusing design rationale information are applicable only in detailed design process stage.

3. Research aim and objectives

As we said above, the long-term aim of this research is improvement of knowledge management process for concept, embodiment and detail design tasks that are parts of complex and long-lasting product development projects which repeat in cycles of 3-5 years. To achieve the long-term aim we need to support and organize simultaneously the processes of knowledge capture (KC) and knowledge retrieval (KR). This research tries to answer following questions:

- What kind of design information structures should be captured?
- How to organize and structure captured information?
- To find and propose appropriate ways of "navigated" (suggested) knowledge capturing that would take as less designer's time as possible

KC and KR are closely related, thus in order to structure KC, the KR should be carefully analysed - we have to understand the designers' needs for knowledge retrieval and the needs for guidance through the problem solving path for embodiment and detail design tasks:

- When and where the need for KR occurs?
- What is the difference in nature of "internal" and "external" knowledge retrieval requests?
- Are there any patterns; could they be classified and/or generalized?
- Based on answers on previous questions, how could the KC needs be suggested?

Moreover, there are some other issues we need to understand:

- the specific characteristics of design processes in small and medium enterprises.
- the process of KR in team communication (group design activity).

4. Design knowledge indexing using relational database

The proposed knowledge indexing method is based on the simplified model of the design process flow represented in relational database. A scheme of proposed system is shown on figure 2. The database contains data about all current and past design projects in particular design office. Proposed database should also include some kind of interface to existing project management system in the design office. The process flow of one particular design project is recorded in the database as list of steps where each step includes a list of actions. Each step and action could be performed (executed) more than once in one particular design task solving process – providing to cover iterative aspects of design. This hierarchy of lists could be treated from two viewpoints:

- from the viewpoint of knowledge capturing it is considered as a "project history" of the currently active or previously finished design task;
- from the viewpoint of knowledge retrieval a recorded "project history" becomes the "guidance" or "advisor" in a situation when the similar or the same class of the project is repeated in the further step of the product development cycle.

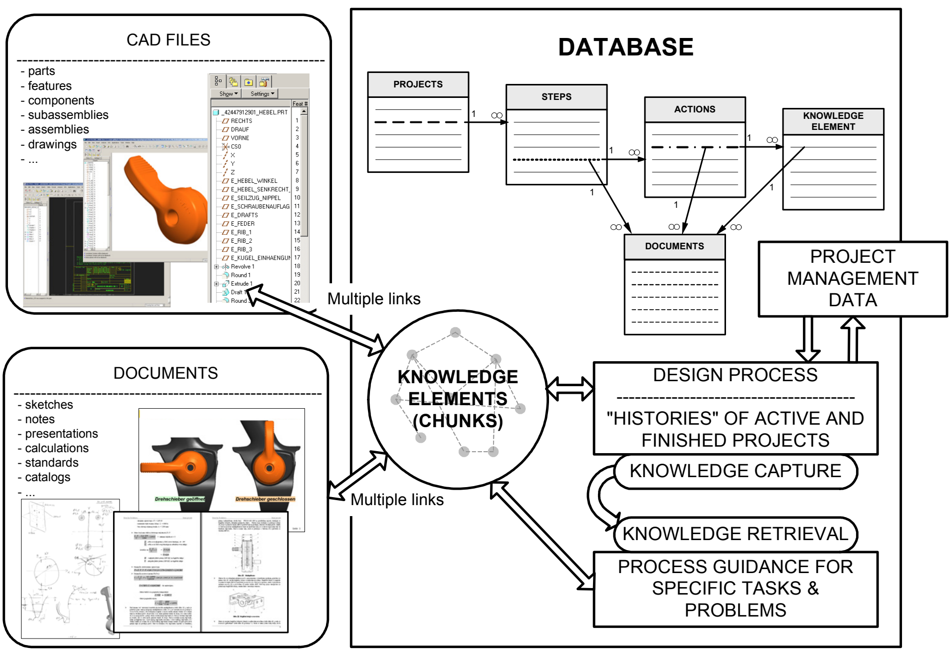

Figure 2. Design knowledge indexing using relational database structure

The design advisor role is to act as "reminder" for simultaneous processes of knowledge capture and knowledge retrieval. The research focus is on repetitive (redesign) tasks. Here we assume that a list of steps and actions valid for particular design task (or class of design tasks) could be reused when such task(s) will be repeated. In other words, knowledge that is to be captured while performing one design task is a candidate to be retrieved in future when a similar or identical design task will be repeated in the next product development cycle. Design process steps and actions together with their attributes store the knowledge about path to design task solution. All other types of knowledge are linked to these main elements of process flow. Or in other words, all the design knowledge is being indexed through the elements of recorded or proposed solution path. Figure 3 is an example of hierarchy of indexing shown through database forms, starting from the level of project step.

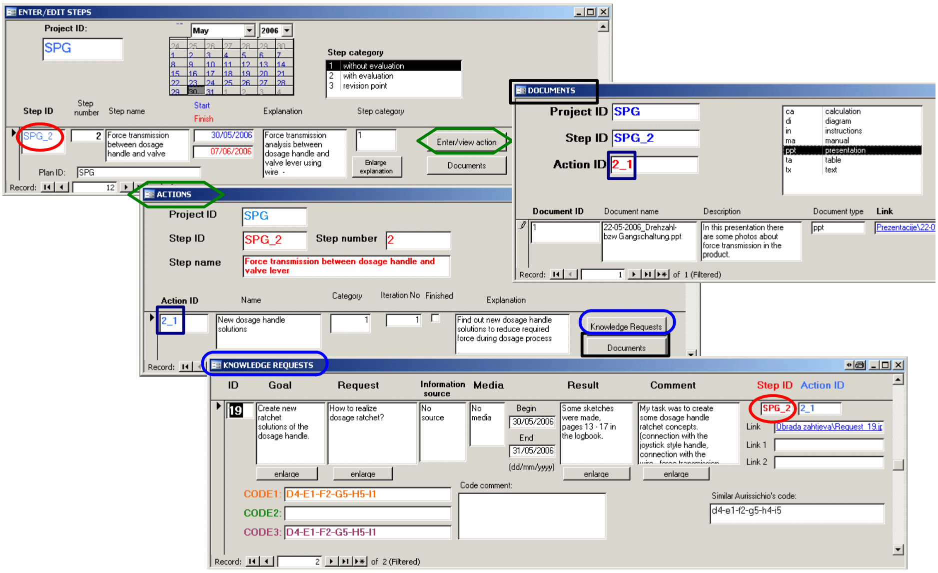

Figure 3. One project step and action with indexed documents and knowledge elements

We assume that linking the knowledge elements to solution path could be the acceptable way of organizing knowledge capture and retrieval processes in a "natural" way for designers. One of our further research efforts will try to model the semi-automatic categorization process for steps and actions to provide the mechanisms for complex searching of similar recorded knowledge elements through sets of project "histories" that have some common attributes.

We consider here a knowledge element (chunk) as a complex data structure that may include a set of various documents that are created independently of each other, but if being connected in particular context as a whole, may give an answer to complex knowledge retrieval request.

Each step and action have a set of related (linked) knowledge elements and a set of linked documents. CAD files are the kind of documents that are treated in a special way – we are currently developing the system which will be able to link geometrical elements e.g. particular features and store the knowledge about elements of CAD files in database. That will allow us to go one level deeper beyond just linking (indexing) the CAD file itself.

Knowledge element (chunk) is represented here as an "abstract class" from which several specific subclasses should be derived and developed. The "abstract class" on the top of class hierarchy contains common attributes and procedures for all subclasses. Deriving and developing subclasses means here defining the set of attributes and behaviour that are specific for particular subclass. In this phase of research we are focused to develop "knowledge request" subclass – or in other words "knowledge request" entity. Here we assume that this will be the most important and most frequent subclass of "knowledge element" in practical usage.

5. Knowledge requests' characterization

To solve some problem designer is trying to find answers on number of questions. So, question asking is a fundamental cognitive mechanism in design thinking, and can be treated as a process [Eris, 2003]. Aurisicchio has developed a taxonomy of knowledge retrieval requests [Aurisicchio, 2005]. The overall aim of his research was to characterise information acquisition in engineering design. He studied request group categories in detail which was the basis for two coding schemes created in one design department of the Rolls Royce company. He has recognized three main groups of information categories: ***context group***, ***request group*** and ***search group***. Each of these groups have further subcategories. The subcategories of knowledge request group are shown in table 2.

Table 2. Knowledge request group of information categories [Aurisicchio, 2005]

Knowledge request	**D**	**Objective**	D1	Information
			D2	Confirmation
			D3	Comparison
			D4	Constructive generation
			D5	Explanatory generation
			D6	Analysis
			D7	Evaluation
	E	**Subject**	E1	Product
			E2	Process
	F	**Response process**	F1	Retrieval – recognition
			F2	Reasoning
			F3	Deliberation
	G	**Response type**	G1	Boolean
			G2	Numerical value
			G3	Symbol
			G4	Text
			G5	Configuration
			G6	Layout
			G7	Source
	H	**Direction of reasoning**	H1	Market need to specification
			H2	Behaviour to behaviour
			H3	Behaviour to form
			H4	X to form
			H5	Form to behaviour
			H6	Form to X
			H7	No value
	I	**Behaviour type**	I1	Intended
			I2	Predicted
			I3	Observed
			I4	Procedural
			I5	No value

To improve and further develop proposed knowledge indexing method it is necessary to develop the suitable taxonomy for each class of knowledge elements. As the first phase of this development we decided to experimentally apply Aurisicchio's taxonomy of knowledge requests as shown in table 2. For this purpose we have conducted the experiment described in following chapter.

5.1 Knowledge requests' coding experiment

Aurisicchio has proposed a coding scheme for his taxonomy in which each element of the taxonomy is indexed with two digits code. One particular request is characterised (indexed) with appropriate combination of elements from each group of categories e.g. D2-E1-F1-G5-H7-I5. The goal of experiment is to investigate the applicability of proposed coding scheme to various classes of design projects. We have started to apply such a coding scheme to a subset of knowledge requests being generated in a development process of the backpack sprayer and duster unit for agricultural usage.

One of the researchers actively participated in the whole design process of above mentioned device. During the project researcher recorded in the log-book his decisions, contacts, calculations, drawings, presentations, CAD models, sketches and time spent for each design task.

From the log-book we extracted 120 knowledge requests, concerning the development of the dosage handle subassembly. All the knowledge requests were recorded in the relational database, each request being associated with one step or action in the design process history (see figure 2).

The process history was divided to 5 steps (design process stages) and 25 actions.

Each knowledge request is further described with following set of recorded attributes: *aim, source, media, start/end date, outcome and comments*. Being treated as a class of knowledge element (chunk), each knowledge request also has a set of hyperlinks to relevant documents and CAD files (figure 2).

Next phase of experiment includes generation of codes for each knowledge request recorded in database. This process is supported with database form and procedure where particular code combination is generated simply by clicking the appropriate subset of check boxes beside rows of table 2 shown on database form – figure 4.

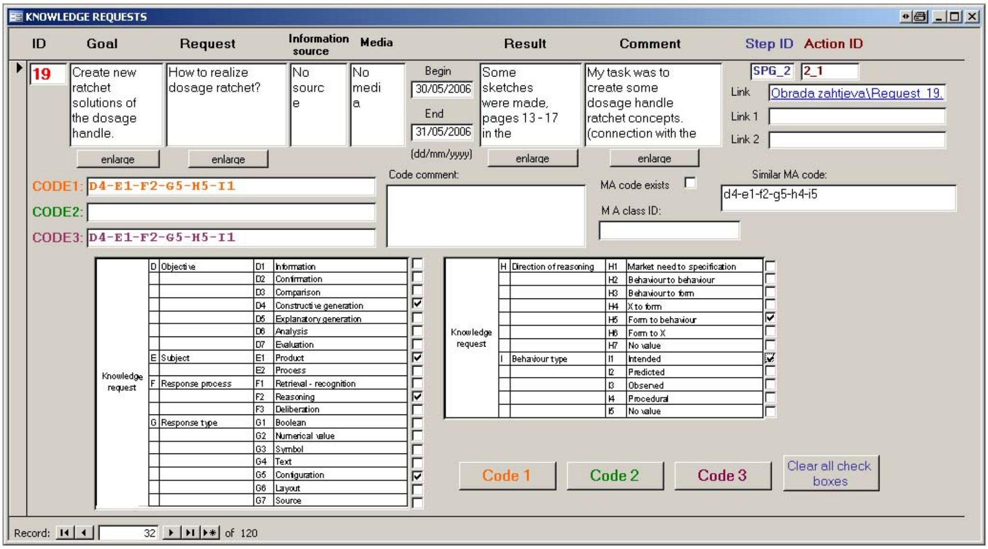

Figure 4. Database form for knowledge request coding

A subset of recorded knowledge requests, together with their code is shown in table 2 as an example of experiment result. In the process of coding, for some requests it was not always easy to decide which subcategory it belongs to. Therefore, we tried to test the repeatability of the generated codes. One week after the first coding, the coding process was repeated on whole recordset of knowledge requests. In this second coding attempt, the result of first attempt was not visible on the form.

Codes comparison showed that for only 48 out of 120 (40%) requests completely the same code was made in both attempts. If we compare only first four categories (D-E-F-G), then there are 82 (68.33%) of knowledge requests with the same code, but if we compare combination of three categories (D-E-F; D-E-G; D-F-G and E-F-G) together, then there are 100 (83.33%) of knowledge requests with the same code. In his thesis Aurisicchio proposed simplified coding scheme for knowledge requests including 17 classes. Each class is one combination of information categories from table 2. Although the simplified scheme characterised the requests in less detail, it proved to be accurate to show clearly the main trends in the nature of the information that engineering designers were interested in. As a result of this analysis there is a need for further investigation on information requests to select those classes which would ensure better knowledge request code repeatability.

Table 2. Development of the dosage handle subassembly: Examples of knowledge requests

	Code	Knowledge request
1	D1-E1-F1-G6-H7-I5	Where to place dosage handle concerning joystick style handle?
2	D1-E1-F1-G2-H7-I5	What is the position of existing holes on joystick style handle?
3	D1-E1-F1-G6-H7-I5	How is the joystick style handle oriented concerning global coordinate system?
4	D1-E1-F1-G2-H7-I5	What dimensions have threaded holes on the one half of joystick style handle which will be used to connect dosage handle?
5	D1-E1-F1-G3-H7-I5	What material was used on the joystick style handle?
6	D2-E1-F1-G1-H7-I5	Do the threaded hole dimensions from CAD model match with standard?
7	D1-E1-F1-G2-H7-I5	What is the diameter of the screw head?
8	D1-E1-F1-G2-H7-I5	What is the countersink diameter for the P6 screw head?
9	D2-E1-F1-G5-H7-I5	Is there any example of the dosage handle which is used on the competitive products?
10	D1-E1-F1-G2-H7-I5	How many partitions has the dosage handle?
…	…	…

To develop more conclusions and extract some patterns, a broader set of design projects should be described, stored and coded in proposed database. We are planning to carry on with several similar design projects while simultaneously improving the database interfaces and procedures. The first design project was completely recorded and described in database by researcher, for the future we are planning that this should be done by designers while working on design projects.

6. Further research issues

The usability and potential benefits of the system will be measured and tested. The designers will be asked to use proposed database tool in their everyday practice. Similarly as in above described experiment, designers should build lists of steps and actions, but now upgraded with predefined "knowledge capture and retrieval slots". The classification and behaviour of these slots should emerge from analysis of experimental usage of proposed system for various classes of design projects.
The following analysis will be made through observation done by researcher, or primarily by designers themselves:

- How often a captured knowledge has been retrieved?
- For suggested (predefined) knowledge retrieval requests, how often the captured knowledge exists, or has been captured in previous development cycle?
- Is the preliminary (experimental) taxonomy of knowledge retrieval and knowledge capture "slots" appropriate, what are the possible improvements?

We will try to use testing process to find possible directions for further, more ambitious research issues – towards complex design knowledge indexing systems.
The developed taxonomy of knowledge retrieval and knowledge capture "slots" will be considered as a starting point for development of the knowledge indexing method on a higher level of abstraction, able to answer more complex or abstract questions, e.g.:

- Did a similar problem arise in some of the previous projects, and if, in which one? If that project(s) is found, how the problem was solved?
- I want to find out more about someone's experience with: this approach; this partial solution,…..
- Which where the main problems in a set of similar previously finished design tasks and projects, what errors have been made?

7. Conclusions

The main advantage of proposed approach to developing a knowledge indexing system is the usage of the same relational database structure and interfaces both for process of experimental analysis used to develop knowledge indexing taxonomy and for process of future eventual practical usage.

All experimental data is automatically stored and structured in relational database, therefore all analyses could be performed very quickly and easily using database queries or spreadsheets.
We expect that the implementation of design knowledge indexing in a relational database environment could provide us with a software technology powerful enough for complex searching and analyses, jet simple enough for experimental development and implementation in practice. Further development may lead to an efficient design knowledge indexing system.

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