INTEGRATION OF KNOWLEDGE BASED APPROACH AND MULTI-CRITERIA OPTIMIZATION IN ENGINEERING DESIGN

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ABSTRACT: The paper contains proposals of integration of knowledge based approach and multi-criteria optimization in engineering design. The proposals reflect a human's way of solving problems. The paper also presents the concept of an environment for computer support of car transmission systems design equipped with the knowledge based and multi-criteria optimization modules.

KEYWORDS: knowledge based systems, multi-criteria optimization, engineering design.

1 INTRODUCTION

This project concerns itself with the computerized support of decision processes in design.

Designing is a multi-stage process which the designer develops while working (Clarkson, Eckert 2005, Clarkson 2006, Pokojski 2004a, Ullman 2002). Obviously, this process is based on engineers' knowledge.

The constant evolution of this knowledge, the changing of outer conditions and the increasing complexity of the tasks make these design processes actually realized in industry become not repeatable (Clarkson and Eckert 2005, Pokojski 2004a, Wallace 2006). The form and structure of a design process is always determined by the designer's decisions; which is also true for the final product, its attributes and characteristics (Gupta et al. 2006, Hatamura 2006, Fujita and Kikuchi 2003, Nahm and Ischikawa 2004). In general, every time when making a decision, the designer wants to achieve certain goals, i.e. fulfill given conditions, realize an assumed function and obtain the intended features to the required level (Clarkson and Eckert 2005, Pokojski 2004a, Sriram 1997, 2002, Ullman 2002). This is mostly an evolutionary process to which changes are gradually introduced (Badke-Schaub and Frankenberger 1999, Clarkson and Eckert 2005, Dorner 1999, Pokojski 2004a). After that their consequences are analyzed and evaluated.

For many years computer tools to support design work and to accompany decision processes have been built. The tools supporting the decision processes make it easier for the engineer to attain the best possible decision. Usually, the tools are integrated with modules directly supporting the designing (Fenves 1998, Fujita and Kikuchi 2003, McMahon et al. 2004, Pokojski 1982, 1990, 2002). Sometimes the decision processes are realized automatically on the basis of knowledge which was either articulated and modeled by the designer or automatically obtained while working. In most cases, however, the designer requires tools which enable a direct and iterative analysis and comparison as well as an interactive operating with a multi-stage decision process.

Decision problems in design processes have been subject to numerous researches in which various methods and formalisms were applied. Part of the researches based on the approach of artificial intelligence – mainly expert systems and methods of case based reasoning (Gupta et al. 2006, Pokojski 2003, 2004a, Sriram 1997, 2002), while others exploited tools of multi-criteria optimization (Kodiyalam and Sobieszczański-Sobieski 2001, Pokojski 1982, 1990, Tooren 2006). There were also attempts to integrate both methods (multi-criteria optimization and artificial intelligence) (Siskos and Spyridakos 1999, Tooren et al. 2006).

The researches also revealed different styles of work among designers (Badke-Schaub and Frankenberger 1999, Dorner 1999, Pokojski 2004a). While working there may occur tasks which are close to artificial intelligence as well as tasks which are typical for the optimization formalism (Pokojski 2004a, Tooren et al. 2006). Both approaches can appear naturally in the same design process and have to be directly integrated then. The paper contains proposals of such "natural" integration reflecting a human's way of solving problems.

This paper also deals with example of decision support systems in engineering design – support of car transmission system design.

2 KNOWLEDGE IN ENGINEERING DESIGN

Usually, a design process is carried out as a sequence of activities (Clarkson and Eckert 2005, Pokojski 2003, 2004a). When referring to an already realized process, we mostly define it by linear sequences of activities (figure 1). But when we want to capture all the potential possibilities a designer has at hand during the whole process and when we also take into account the computer environment which is at his disposition, we usually employ the maze model (Pokojski 2003, 2004a) (figure 2). In contrast to the linear model, the maze model is more capable of portraying the dynamics of proceeding in a design process. The activities a designer manages and applies are accompanied by knowledge sources (Pokojski 2004a). The realization of a given activity enriches that knowledge (Pokojski 2004a).

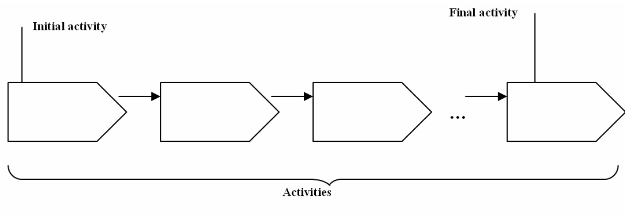

Figure 1. Linear model of design process.

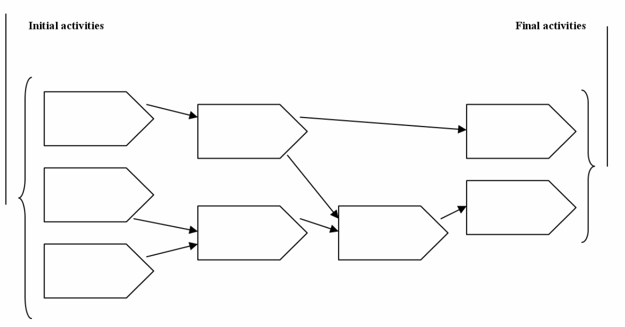

Figure 2. Maze model of design process.

Applying his knowledge the engineer may draw a particular conclusion at a certain stage of the design process which results in a new element of the actual design process and also of the product being designed. There are various sources where a designer can find knowledge which he needs for his work. One of the most popular, however, are other designers (Wallace 2006). Consequently, tools providing other engineers' knowledge are met with high approval (Clarkson 2006, Clarkson and Eckert 2005, MOKA 2001, McMahon 2004, Pokojski 2002, 2004a, 2005, Sriram 1997). With the help of these tools, conclusions and reasoning can be exploited to solve new design problems; regardless whether they are routine, innovative or even creative. It must be admitted, though, that up to now computer implementations of that nature work best in the case of routine examples (figure 3).

The problem in the figure 4 (Pokojski, Okapiec and Witkowski 2002) refers to the geometric modeling of a tooth wheel and its respective clutch and to the calculation of both. The calculation is done algorithmically. For the achieved results a geometric model of the tooth wheel and the clutch is generated on the basis of the modeled knowledge.

With many design works we encounter steps which are typical for the case based reasoning method (Gao, Zeid and Bardasz 1998, Maher and Pu 1997, Pokojski 2003). The engineers obviously like to return to processes they realized in the past. They often use them as comparative material to their actual tasks and sometimes even take an effort to adapt the old example to the new one. Scheme in figure 5 depicts such an attempt.

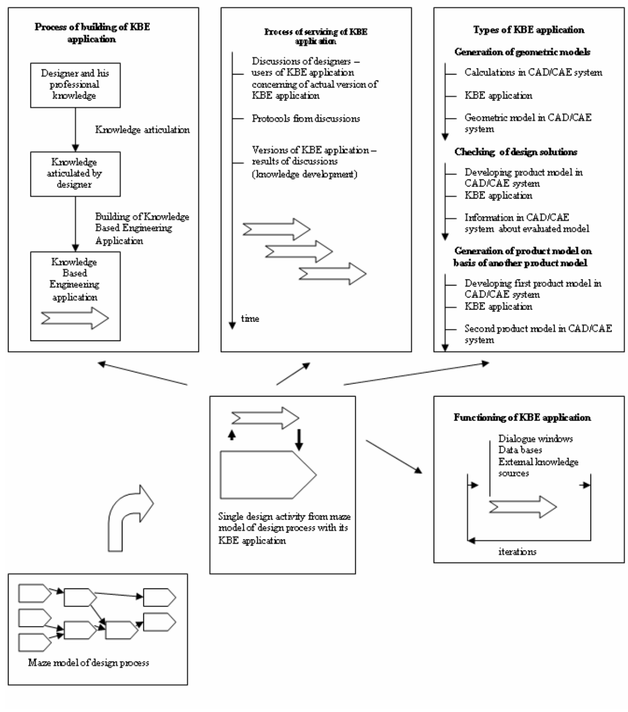

Figure 3. Maze model of design process and Knowledge Based Engineering (KBE) application (issues considered in project) supporting single activity.

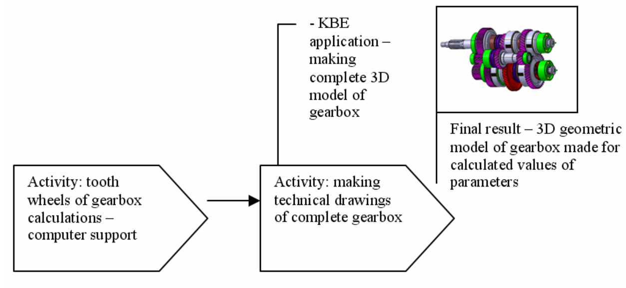

Figure 4. Exemplary design process – designing of car gearbox; KBE application supporting single activity.

On the basis of his professional knowledge the engineer can make many inferences which may result in various final solutions. But in general, the designer aims at solutions which meet certain conditions; for example: fulfill the given function best, find the solution which is easiest to realize or to assemble etc (Clarkson 2006, Clarkson and Eckert 2005, Pokojski 2004a). We can say that the designer looks for a kind of optimization between a defined range of final criteria and an applied set of decision variables. In this situation the connection between the criteria and the decision variables is generated by inferencing or searching and adapting.

With many design works inferencing may lead to a problem with a big number of solutions in implicit or explicit form. Sorting these solutions while inferencing is possible but in most cases it would be quite work intensive. However, we can do a selection by applying the method of multi-criteria optimization (Ehrgott and Gandibleux 2002, Hong, Hwang and Park 2004, Hwang and Masud 1979, Hwang and Yoon 1981, Keeney and Raiffa 1976, Marler and Arora 2004). For that purpose the engineer models the problem, defines his preferences and solves the problem of multi-criteria optimization.

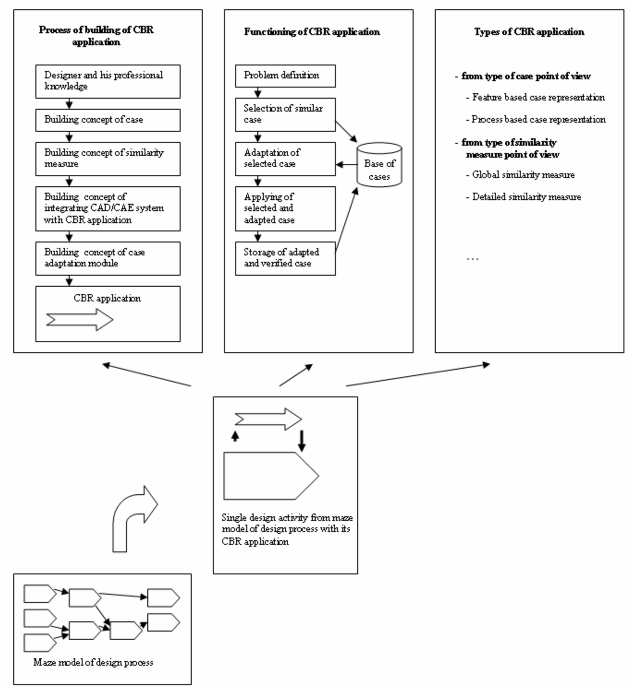

Figure 5. Maze model of design process and Case Based Reasoning (CBR) application (issues considered in project) supporting single activity.

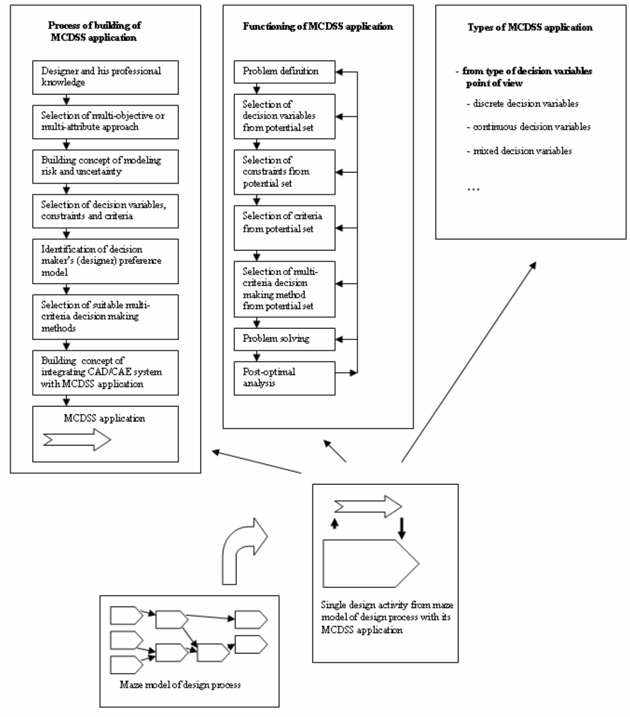

Figure 6. Maze model of design process and Multi-Criteria Decision Support System application (issues considered in project) supporting single activity.

The above mentioned example concerning the tooth wheel is a typical example of this problem, which means the calculation may yield many satisfying solutions. But often it is not easy for the designer to compare all the different solutions (Pokojski 1982, Osiński, Pokojski and Wróbel 1983). Because of that it is advantageous to add an optimizing module to the calculation program (figure 6). With it we can establish the optimization task for tooth wheels (see figure 7) and as a result one of the most preferred solutions is selected and can then be sent to the module that generates the geometric model of the tooth wheel and the clutch on the basis of the modeled knowledge.

This shows that design knowledge always takes priority, because it is the basis for generating concrete solutions to concrete problems. This knowledge evolves (figure 8). At certain stages we may apply the KBE, the CBR or the multi-criteria method (figure 9).

Quite frequently, several multi-criteria optimization tasks arise in one single design process and have to be realized at different stages. Figure 10 presents such kind of problem. The considered tasks don't arise alone but are accompanied by the dependency of parameters (figure 10B). By changing the order when solving the sub-problems we can destroy the initial structure of the problem and obtain different final solutions (Pokojski 2002, 2004a).

In a design process single optimization tasks don't follow one after the other. Stages of the knowledge based inferencing are in between of it. They base on knowledge which leads to the establishing of further optimization tasks (Pokojski 2004a).

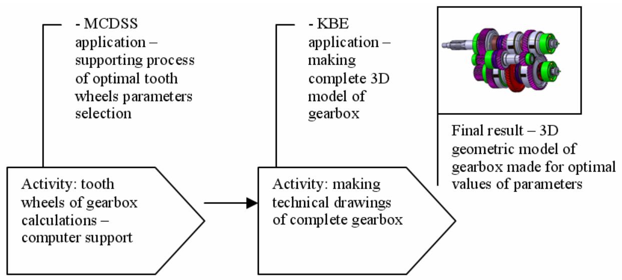

Figure 7. Exemplary design process – designing of car gearbox; supporting single activities by MCDSS application and KBE application.

We shouldn't forget, however, that in each of the discussed situations numerous indirect and partial results may appear which are consequences of the iterative character of design activities (Badke-Schaub and Frankenberger 1999, Dorner 1999, Pokojski 2004a), (figure 11).

3 MULTI-CRITERIA OPTIMIZATION IN ENGINEERING DESIGN

During the last thirty years many works have been published concerning the application of multi-criteria optimization methods in design (Pokojski 1982, Hong, Hwang and Park 2004, Maler and Arora 2004). The works refer to the design process as a total or only to its parts which were then regarded as one single problem of multi-criteria optimization (Kodiyalam and Sobieszczański-Sobieski 2001, Pokojski 2004a, Sobieszczański-Sobieski and Haftka 2001).

The approaches presented in literature exploited the multi-objective (Hwang and Masud 1979) and the multiattribute (Hwang and Yoon 1981) methods of optimization. Special attention was given to the preferences of the decision maker (Keeney and Raiffa 1976) and to the communication between the human and the computer system (Ehrgott and Gandibleux 2002). Effective interfaces were worked out as well as a quite functional standardization of Multi Criteria Decision Support Systems (Siskos and Spyridakos 1999).

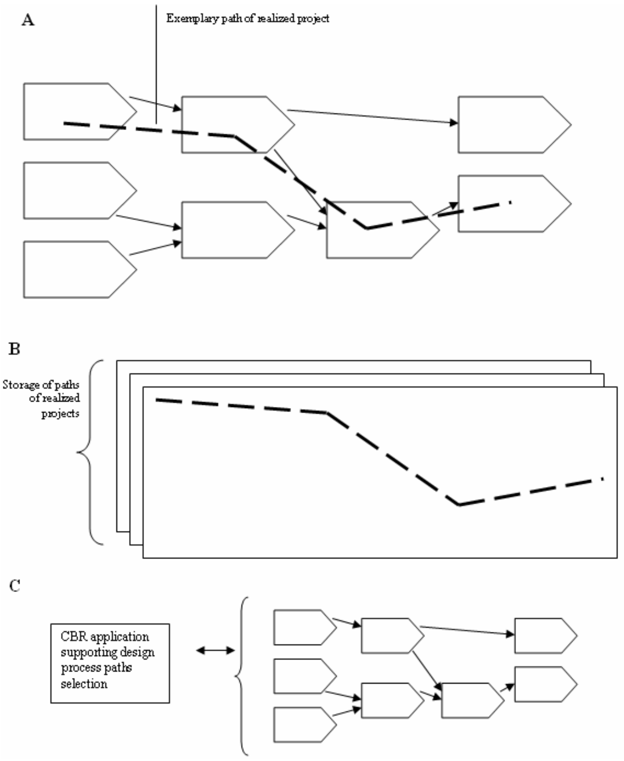

Figure 8. Maze model of design process and paths of realized projects. A – exemplary path of realized project shown with maze model, B – storage of paths realized in past projects, C – CBR module supporting design process paths selection.

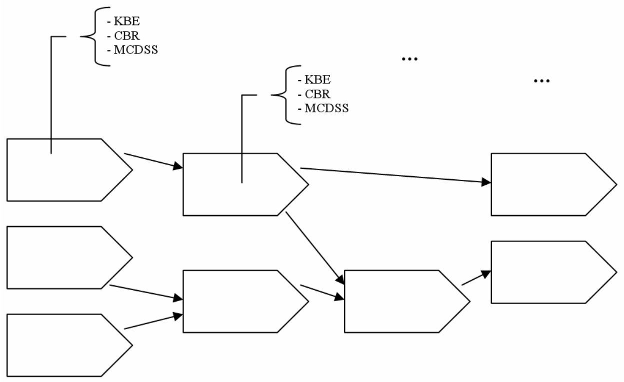

Figure 9. Maze model of design process and potential possibilities of supporting single activities by KBE application, CBR application or MCDSS application.

The methods for solving optimization tasks of a decomposed structure are especially interesting. An example to such an approach is the problem in the figures 12, 13 and 14. There are several ways of solving these kinds of problems (see Chanron et al. 2005, Kodiyalam and Sobieszczański-Sobieski 2001, Pokojski 1982, 2004a, Sobieszczański-Sobieski and Haftka 2001).

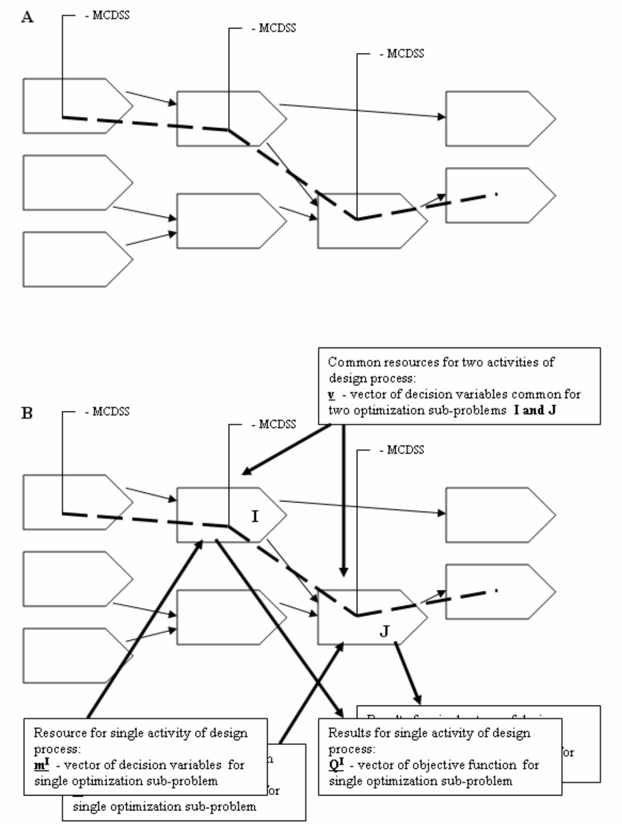

Figure 10. Maze model of design process with integrated few MCDSS applications supporting different activities. A – maze model together with MCDSS applications, B – two activities I and J, and their multi-criteria optimization problems and relationships between their components.

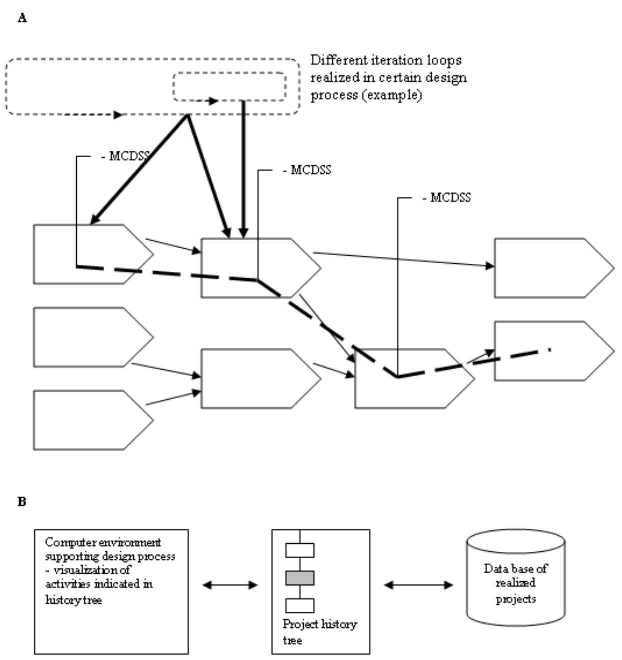

Figure 11. Way of solving problems done by human designers. A – exemplary path and iteration loops. B – concept of tool responsible for project history management.

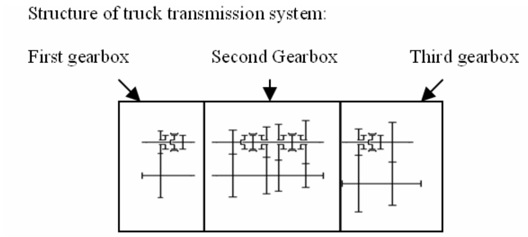

Figure 12. Exemplary application supporting truck transmission system design – possible structures of transmission system.

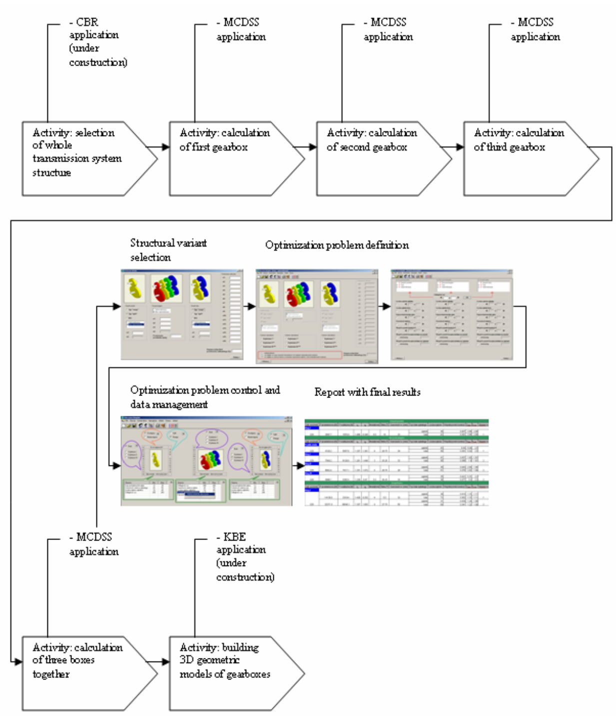

Figure 13. Exemplary application supporting truck transmission system design – scheme of application with supporting modules.

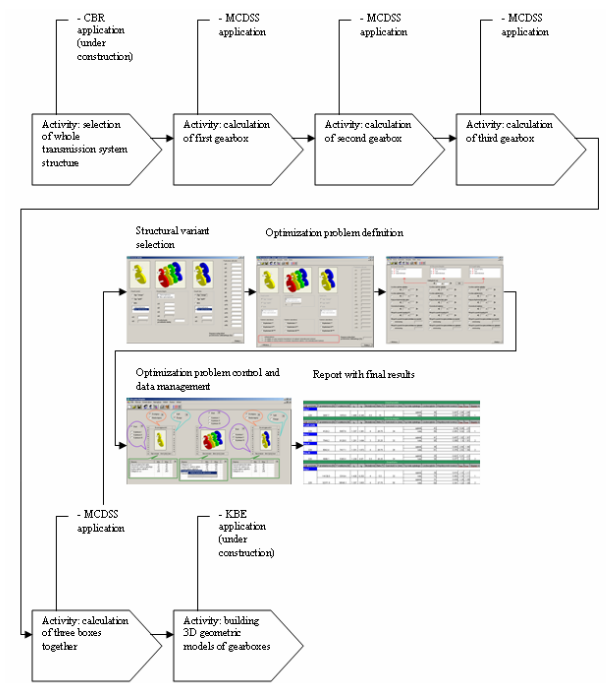

Figure 14. Exemplary version of application from figure 13 supporting car transmission system design (under construction); added functional and calculations modeling.

4 DECISION MAKING IN ENGINEERING DESIGN

In the two previous chapters two different approaches of solving decision problems in engineering were discussed and ways of their integration were shown.

Decisions are constantly made while designing during which time the process proceeds step by step. In its course the designer may take a decision at a certain stage, whereas at another stage a decision comes iteratively.

Sometimes particular fragments of the design process are only the source of knowledge for the decision making, that means the selection of a concrete variant and have no direct influence on the applied design solutions and the selected parameters.

Many of the designer's decisions are made in risky and uncertainty conditions (Pokojski 1990). There are known and used approaches for this group of problems. They are in principle modifications of classical decision methods.

Only when a design project has come to an end, we are able to realize that the decision making in the process yielded many elements as well as numerous partial problems, lots of attempts, hypothesis and iterations (Gupta et al. 2006, Hatamura 2006, Pokojski 2004a).

Each of these elements stands for some kind of result or some kind of evaluation of the result; but what is even more important, it embodies a concrete future decision or a future task. From this phenomenon we can conclude that the most important function of the computer environment, which tries to integrate the above approaches, is the management of the realized tasks and their solutions with respect to their real functioning.

Known attempts of this class of environments for engineering tasks are the works of Jerzy Pokojski and Krzysztof Niedziółka (see Pokojski 2004ab, Pokojski and Niedziółka 2005, 2006). Figures 12, 13 and 14 illustrate the basic functions of such an environment. Figures present also its structure and interface.

5 CONCLUSION

The proposed approaches to the integration of knowledge based methods and multi-criteria optimization in engineering design try to eliminate shortcomings which arise with applications dominated by one class of tools (artificial intelligence or multi-criteria optimization). Between these two tools, in case of a concrete engineering problem, we can estimate a certain substitution rate depending on different details of the knowledge based approach and the multi-criteria optimization in this particular situation.

From the author's experience the most important factor in building an integrated decision making model of a problem is the identification of a high quality domain knowledge model by a competent human expert. Often it is difficult to do that in advance. We have to prepare the identification (process) of the most efficient proportions between these two tools and the direct areas of their application. This can be done with computer experiments by a human expert. But to be more efficient we need a flexible computer environment with a set of suitable capabilities.

The author and Krzysztof Niedziółka are developing an environment which goes in this direction.

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