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Engineering Design in Integrated Product Development
Management of Design Complexity

INTELLIGENT PERSONAL ASSISTANT IN ENGINEERING ACTIVITIES

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Abstract: *The paper presents the basic concepts of a computer tool known as an intelligent personal assistant for designers [5, 28]. This software offers the designer the possibility of storing and managing his personal knowledge. Additionally, the personal assistant can integrate most of the computer resources in use. The article concentrates mainly on the conceptional layer of the personal assistant. Less attention is paid to the issues of implementation and realisation in real life (issues which were widely discussed in other papers [5, 28]).*

1. INTRODUCTION

The paper focuses on computer management and knowledge storing, which is indispensable for the realisation of design works. The 1990s brought a broad awareness of the fact that every activity of an engineer is based on a certain knowledge. And the awareness that knowledge determines the quality and the attractiveness of a product [7, 8, 24]. But the designer's knowledge is also a source which plays the main role in the design and production process. Nowadays, it is taken for granted, that more design works are realised on the basis of a wide knowledge than on the application of methods supporting engineers' work.

When analysing design works which were carried out in industry, it becomes obvious that an engineer's knowledge undergoes a permanent and dynamic development [6, 13, 14, 17]. Every new design task, every realised project can bring about a new element of knowledge, which is derived from new experiences. Mostly this kind of knowledge is directly generated by those who design. This is an individual process. The knowledge appears and is remembered by the designer. Sometimes, however, the knowledge is articulated as written notes. The notes may be taken chronologically, according to tasks, etc. In general they are meant for private use and are not subject to any auto-censorship. The notes often contain documents like texts, sketches and schemes. Often the materials arise directly in the design process. It may happen that they later become essential sets of information in various forms together with helpful comments [32, 34, 35]. Keeping the notes in their original version avoids future problems in understanding them. Familiar design situations will be found easier and one's own and actual way of thinking will be easier to recall.

Team work often brings about valuable and comprehensive design knowledge. Discussions and interactions may direct the solution path of a certain problem. Obviously, the knowledge appearing accidentally while cooperating isn't unified.

In general each member of a team acquires different individual knowledge. The knowledge may vary only in shades, but essential differences which may be the key to the solution for the whole project can be observed as well. These deviations result from the designers' education, personal development, individual professional background and career.

An engineer's knowledge represents significant value and can become the basis for the creation of new solutions in design problems [14, 15, 18, 19, 20]. Their availability has a decisive influence on the gained essential results as well as on the efficiency of the work process.

Consequently, it is only natural to try to exploit that knowledge in the best possible way. A relatively

suitable solution is to capture the engineer's knowledge from the designers and to store it with the help of special computer tools [5, 28]. But the question arises whether the acquisition and storing process should be organised exclusively by the designer or by the knowledge engineer as well. The paper starts from the assumption that the computer storing of the knowledge has to show a very reliable picture of the professional knowledge of the designer in question. Therefore a computer notebook has to be built for him which allows the entry of the personally generated knowledge. The basic advantage of such an approach is the high quality of the introduced knowledge and the fact that the knowledge which is directly used by the designer obtains its computer representation. The proposed computer notebook should become one of the basic tools in the workshop of a professional designer. The designer who tackles a new problem should have the possibility of a quick access to knowledge and information stored earlier by him. And he should also have the possibility to obtain information about projects similar to the ones he is actually working on and to the background resulting from earlier applied knowledge. It is also assumed that the tool facilitates the organisation of the individual wealth of knowledge and allows controlled admittance to other designers.
Additionally, that tool should offer the possibility to integrate the computer systems most frequently used by the designer. The paper presents the basic concepts of a software which we are going to call the intelligent personal assistant of the designer. For many years this was the topic of researches carried out by the author and his associates. The basic results of the works can be found in [5, 28]. The following treatise actualises the results presented in [28].

2. KNOWLEDGE IN THE DESIGN PROCESS

The knowledge which is necessary during a design process can be classified according to the following criteria: content core, form, kind of activity with which it is connected; as well as according to the origin and different source of the knowledge. In literature many concepts for the classification of knowledge can be found [8, 9, 17, 24, 35]. In the subsequent case we exploit approaches which have an essential and practical context, that is to say categorisation based on core criteria as well as according to the kind of representation and forms of storing [24]. A relatively complete proposal is shown in [24]. [24] contains a relatively complete scheme. It is based on the assumption, that knowledge has to be joined to the elements of the design process and its structure such as:

- terminology – set of terminologies used in a certain domain,
- specification of the product,
- general limitations,
- conceptual design – ideas, rules,
- physical design – aspects connected with form giving,
- design rationale,
- design process in the context of its activities,
- rules,
- strategies,
- associations.

When approaching the problem of knowledge representation in technical applications, it is quite convenient to use rule and object formalisms.
Knowledge can be written in different forms; as procedural, declarative or multimedia knowledge [32]. Procedural knowledge deals with problems where suitable algorithms are built. Declarative knowledge characterises a form which is used in expert systems. Multimedia knowledge implies written and visual information. Systems, whose activity is based on knowledge, can be divided into two groups [27]:

1. Systems in which the process of interpretation is realised by the computer (procedurally working applications and expert systems)
2. Systems where the interpretation is done by a human (multimedia information).

The second group shows the variety of computer means available.
Each of the groups has a different development history. The first group - in contrast to the second one – is in general marked by a great intensity of work, increased efficiency and is, as a rule, in most cases less flexible. The tools of the second group allow a relatively easy actualisation of the knowledge and its servicing, but at the moment they don't tolerate a high level of automation [27, 34].
The following chapter shows how design knowledge formalisation can be performed while applying the above typology and by writing it within the system belonging to the class of a designer's intelligent personal assistant.

3. FORMALIZING OF DESIGN KNOWLEDGE

The chapter focuses on creating a formal representation of design knowledge (by the designer) . The conceptions taken up presuppose that actions, which the human can relatively easily carry out by himself, will be left with him. This means processes of knowledge generation, associations and interactive model creating – in general as well as in detail. The proposed concept aims at a high degree of flexibility by involving a multitude of components. Several concepts arose from numerous contacts with design-

ers in industry (and their surrounding) and were verified in a row of prototype applications [5, 28].
Irrespective of the used classification we have to state that the knowledge which the designer processes, has mostly a unified and coherent form. Designers associate knowledge and its development with certain professional activities such as calculating a particular product, or its form giving according to stated recommendations. The knowledge which accompanies certain activities undergoes to permanent development. Activities which are not used, may as a result cease evolving, while new ones may appear and replace them. It is quite difficult to catch the dynamic of the designer's knowledge development. To make it comprehensible we start with a concrete example of a certain activity carried out by an engineer [28].

Example 1.1.

We imagine a designer who has begun his professional career and is working on the calculation of tooth gears [28]. Below we show the continuing stages of how the knowledge concerning the mentioned activity – calculating tooth wheels is emerging.

1. Stage 1. The designer acquainted himself with the calculation of tooth wheels by studying the corresponding specialist literature. He became familiar with articles, the monographs and the standards defining the calculation process. Additionally, the designer saw computer programming works calculating pairs of cooperating tooth wheels. If we had tried to capture the knowledge acquired by the designer at this stage, we could have easily done it by using multimedia representation. But it would have been much more difficult to build a computer programme (procedural knowledge) or an expert system (declarative knowledge).
2. Stage 2. The designer builds a computer programme based on the knowledge from stage 1. The programme is in the form of a procedural knowledge representation. It significantly improves the process of introducing certain calculation classes. Unfortunately, some cases cannot be calculated by it (for example very big wheels) and they have to be calculated manually. Often a mixed approach is applied for solving various design problems: using the computer programme and selecting the necessary data in literature. This way knowledge increases. He starts to take notes and to write articles on that topic.
3. Stage 3. The designer becomes familiar with the technology of an expert system. He tries to build an expert system himself which suggests the way non-standard examples can be calculated. The knowledge which the designer has gained by then obtains a new form – that of declarative knowledge.
4. Stage 4. The designer tried to build an application which is able to generate a geometric gear model on the basis of his knowledge. He exploited tools of Knowledge Based Engineering [32]. As we can see the designer's knowledge about the geometry modelling of tooth wheels developed into a declarative-procedural form.
5. Stage 5. The designer applied all the tools being at his disposal. His experience and knowledge evolved and he expressed his new knowledge in the form of multimedia notes.

Obviously, the constructed theoretical example is not complete. In reality it would have been necessary to add many more intermediate stages, explaining the development of the knowledge concerning the application of optimisation methods, the methods of finite elements and the simulation methods. But then the majority of the presented achievements would have acquired the attribute called versioning. Consequently all states could have been enumerated in the example above. The exactness of the version-storage of different knowledge components depends on the designer. He personally decides about their level.

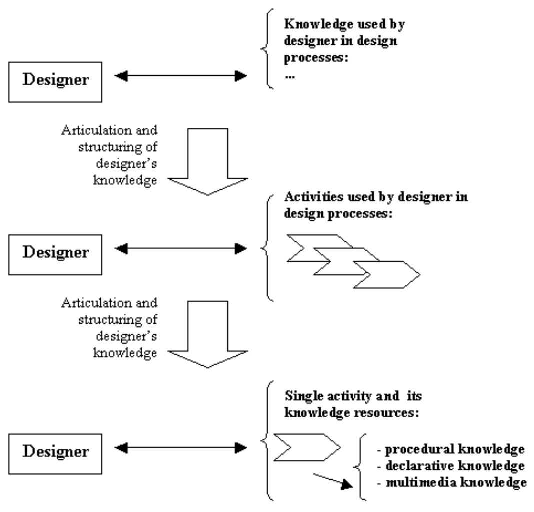


Fig. 1. *Designer's knowledge structuring.*

In the given example the knowledge creator was the designer (figure 1). The knowledge was his own work. In fact, he was in charge of the most complete picture of that knowledge – only at different moments of time. In principle this process was accompanied by specific computer articulation of the knowledge. Thus certain representations were achieved and stored. After inserting the different knowledge components in the time axes in the stages of knowledge development, the whole process was given the dimension of storing the history of the knowledge development [28]. Returning to the different stages we can try to make out which knowledge the designer had at the moment when he created the given knowledge component. That means what preceded that moment. Additionally, we can trace back what chunks appeared and when for the first time and what changes they went through later. The way of integrated storing various forms of knowledge representation applied in practice, which we propose, allows to approach a real process of knowledge development with the human. The figure 1, 2 show in a schematic way the designer's operations and using his individual knowledge store.

Up to now we mainly concentrated on the problem of single activities. Obviously, designers master a bigger number of activities in their professional knowledge store; there may be scores or even hundreds of them. Moreover each activity contains its own knowledge store which can be captured in the context of its historical development.

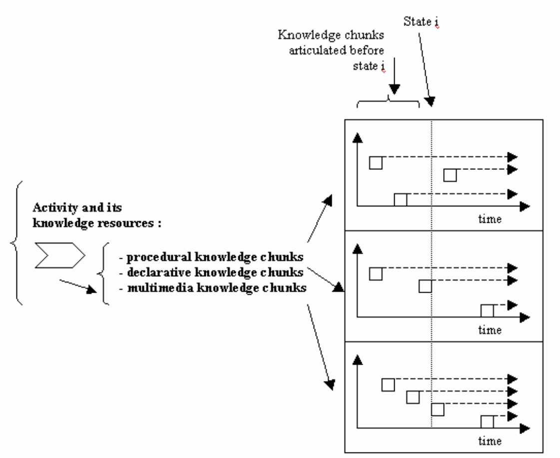


Fig. 2. *Single activity – knowledge storage and management.*

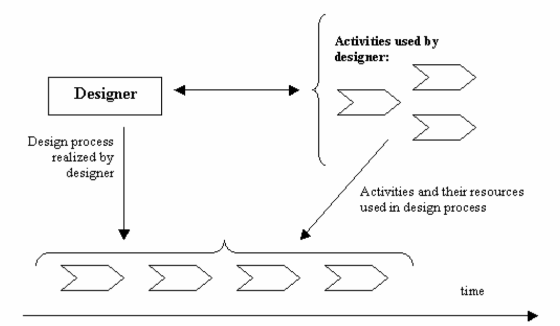


Fig. 3. *Activities used by designer in certain design process.*

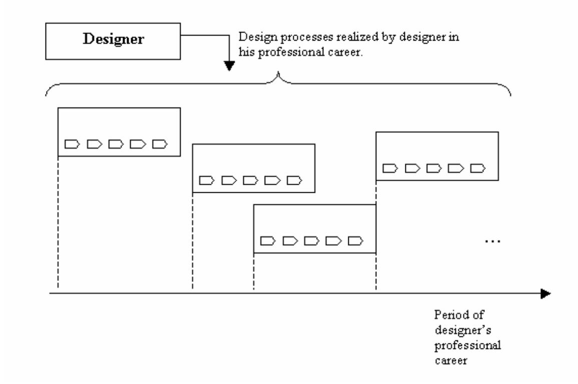


Fig. 4. *Design processes realized by design in his professional career.*

While working, on a (design) project designers use activities originating from their individual professional workshop. Setting about the given work the designers quickly check whether their professional workshop facilitates all foreseen activities that could become necessary. If some of them are missing the designer starts to look for knowledge and tools or even people who poses that knowledge. Often at the beginning of a work not all specifications of the necessary activities can be accomplished, but their amount may change in the course of the design process. Additionally, knowledge connected with different activities develops as well (figures 2, 3, 4).

In the introduction of the article we pointed out that experience, i.e. earlier realised projects, has an essential influence on the actual design task. In general the realisation of a project brings knowledge about plans of the applied design processes. The plans are compiled by a collection of used activities. In a definite moment of time during the realisation of the design task certain activities had achieved a certain stage of their development. Mostly the established plan is the result of experience and of the actual knowledge stage. The designer's own experience and knowledge originating from other knowledge sources might have inspired the creation of the plan. The designers mostly remember very well the processes which they have realised. But they never take down any notes of their details. The possibility to return to processes which have been realised earlier and also the possibility to return to the different stages of a certain activity would be very helpful. On the bases of our concept you can try to build an integrated environment for the support of design processes which are a repository of design processes already realised or to be realised in future (figures 5,6). In spite of its advantages, the concept is relatively stiff. The author of this article made attempts to make it more flexible [28]. By exploiting blackboard architecture [9, 12, 16] a fast integration of new activities and their knowledge resources becomes practicable. Blackboard architecture and especially its shared working space, that means the blackboard, fulfils the role of a repository for the actual process. Thus the process plan evolves as shown in figure 7.

A very convenient construction is the project history tree which is set up on the events generated by the different activities. In general this construction is intuitionally perceived by the designer and doesn't cause him any problem. Additionally, the activities are described by essential data which define their connection in the designer's individual knowledge store. With the history tree tracing for further activities in the current project becomes very easy. The tracing can also be realised as a feed back; from the node of the history tree to the relevant application, the corresponding set of data, the corresponding stage of the application (figure 8).

When the case-based reasoning [15, 23, 29] method is applied the design process becomes the case which is stored with the exactness including all relevant events. The description of the case can be enriched by adding to each node of the history tree information belonging to the design rationale class. Consequently, looking for a suitable case can be done on the basis of direct information from a process (activities, parameters, data) as well as on information of the design rationale kind (description of the discussion, argumentation). The process of generating information of the design rationale kind [25, 31] can also be realised by exploiting individual resources of the intelligent personal assistant [29].

Not only do we want to present the concept of a designer's intelligent personal assistant, but we also want to direct attention to team work matters. As we know, designers can decide which knowledge components shall be made accessible for other designers and to what extent (figure 9).

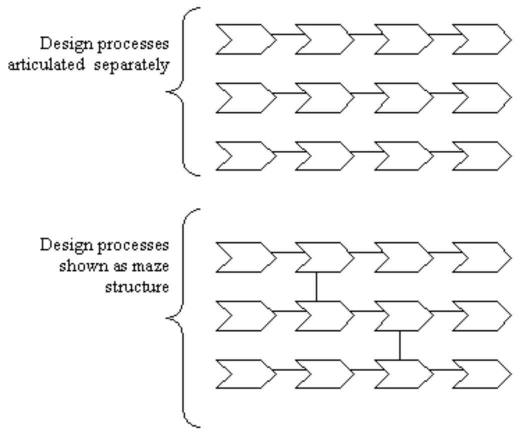


Fig. 5. *Evolution of design processes structures articulation.*

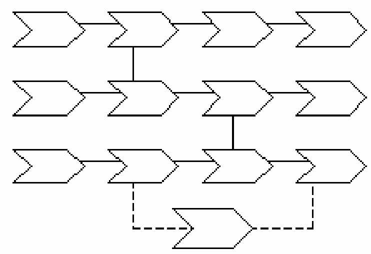


Fig. 6. *Adding new activity to existing maze model of design process.*

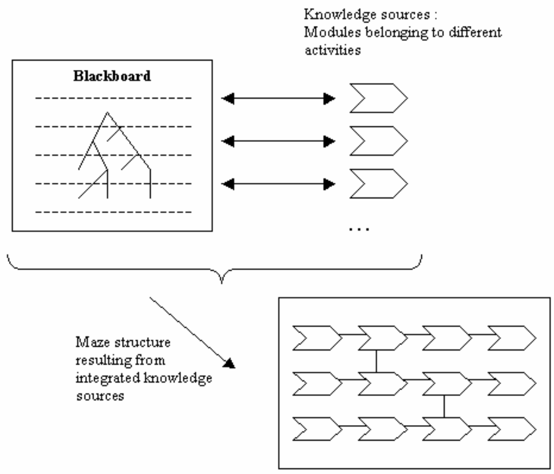


Fig. 7. *Blackboard architecture as integration tool.*

From the today point of view the designer's personal assistant is regarded as his individual knowledge repository. It has to function as a place for storing information and knowledge. Functions for the knowledge management are already being planned. One interesting feature of that concept is its integration with multi-criteria optimisation methods [28] (figure 10). The idea of joining these two approaches originates from the fact, that each activity can be connected to a multi-criteria optimisation task. The tasks may have the goal to find the best fitting set of parameters for the given activity. Moreover, the knowledge which we obtain as a result from such a task may effectively support the process of searching for further activities in the actual design process. But we should know that with a design process like this activity sequences turn up, which do not necessarily lead to a best value of parameters from a global view. To improve the general results special multi-criteria optimisation algorithms have to be applied for problems with a decomposed structure [28] (similar methods appear in multidiscipline optimisation [21]).

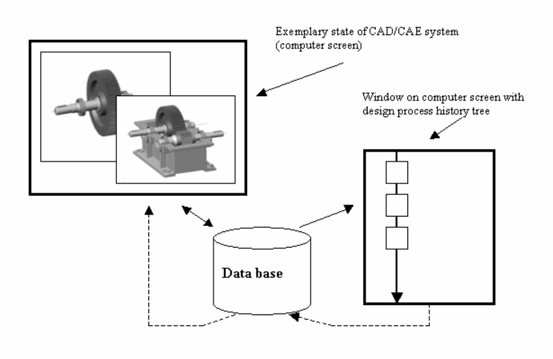


Fig. 8. *Integration of history tree with computer systems used during design process.*

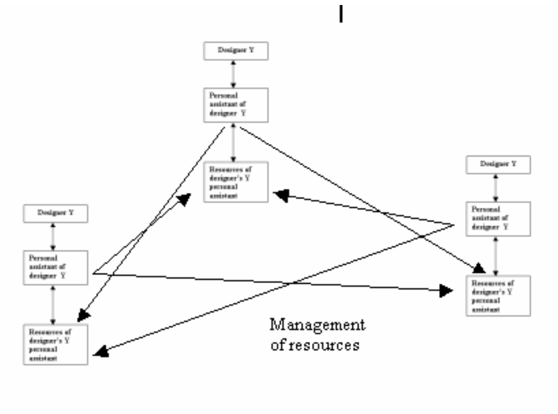
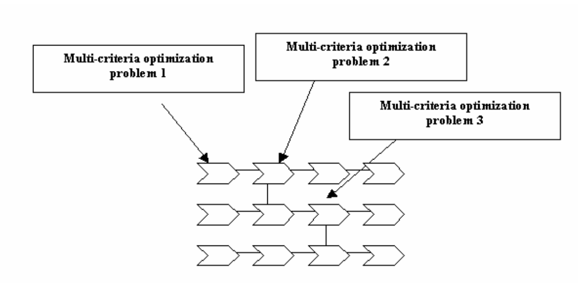


Fig. 9. *Management of personal assistants resources.*



Fig, 10. *Maze model of design process integrated w multi-criteria optimization problems.*

4. SOFTWARE IMPLEMENTATION OF THE DESIGNER'S PERSONAL INTELLIGENT ASSISTANT

The designer's personal intelligent assistant is in principle the concept of a certain software, which has to organise the process of gaining, storing and managing individual knowledge [28]. The concept is confined to basic terms and the relations (connections) among them. As a concept it can be realised in different environments with the help of different groups of computer tools. Up to now the attempts of implementing this concept were mostly based on more than one computer tool. Data basis, expert systems and the programming languages MS Visual Basic and MS Visual C++ played the most important part in it. Sometimes the MS Excel was applied which then functioned as shared working space.

Applications of a personal assistant have been made for various uses [5, 28]: to support the design process of a heating system, the braking system of cars, chassis of planes, furniture etc.

Each of the above problems must be examined under the following aspects [28]:

1. the design process and the knowledge connected with it,
2. the computer tools being available and used,
3. the conditions of the hardware and the networks,
4. the economic limitations with the project realisation.

Implementation examples are presented in the works [5, 28].

The biggest challenge with this class of applications is the fact that many different tool technologies must be used, which are all relatively new and of a higher standard. To meet this challenge it was very beneficial to form a working team. Two persons of the working team were appointed the main executers supported by a big team of consultants, who had to provide detailed solutions to the occuring problems. The consultants also had to work out new solutions when necessary.

An important finding made while carrying out those works was that many ideas and concepts had already appeared in the designers' imagination before the application of the personal assistant was built [28]. They gradually became obvious as the application was developing. When building the application it was very helpful to use software models of former applications. Applications belonging to MS Office are very useful during those activities because of their big popularity.

In the row of implementations with the applications of the personal assistant two functions could be successfully joined: the personal knowledge repository and tools for the integration of computer applications, used to support design tasks.

5. CONCLUSIONS

The paper shows basic concepts and ideas which form the basis software of the class of an intelligent personal assistant for the designer. The presented solutions were tested as prototype implementations. Some of them gained entry to systems of every day use. But there is also an application which has industrial format features. It will be thoroughly integrated with the customer's actual computer resources.

The understanding gained in the tests up to now encourages further concept development. Current projects concentrate on the idea of equipping the personal assistant with tools for text processing and to increase the exploitation of the case-based reasoning method. One of the biggest shortcomings of the software tools used up to now was the variety of integration solutions. The works actually being done intend to reduce this number.
The goal of other experiments is to form a stronger connection between the concept of the personal assistant and computer tools supporting the geometric modeling process.

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