Personal Knowledge Management in Engineering Design – Issues, Concepts and Applications

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Abstract: The paper presents the basic concepts of personal knowledge structuring in engineering design with a computer tool known as the personal assistant of designer. The article concentrates on the main conceptual issues of the proposed approach.

1 Introduction

The paper deals with the knowledge management in engineering design. In the 1990s an in-depth understanding awakened that professional engineering knowledge has a value in itself for those who design and create new concepts of products [CE05, Po04, Ul02]. Engineers started to realize that their own knowledge resources and abilities have a direct impact on the creation of new products for the market. It became obvious that those who possess the wider knowledge are faster with bringing out new products. As a consequence professional engineering knowledge became one of the most important company resources. Researchers noticed that when creating a new product the wealth of knowledge is more important than engineering methods. Because of that decision makers came to the conclusion that knowledge once acquired should not be lost as it can be used again. So companies set about to store the knowledge for internal use and built storage and management systems which kept their processes, procedures, corporation rules, realized projects, standard documents etc.

The storing and delivering of knowledge were the basic functions of such systems. It didn't take long and the necessity to cover all engineering domains by those systems became evident. But the acquisition of engineering knowledge turned out to be very difficult and time consuming. The kind of knowledge needed for engineering design, its storage, the changes it undergoes with the designer's professional career and the possibility to pass on the knowledge of an experienced designer to a novice have been the subject of numerous researches [Ce05, Ma01, Po04, Re01, Ul02].

The research works [Po04, Ul02] also revealed that the knowledge of an individual designer is the result of his education, training, personal development, professional experience etc. It goes without saying that an engineer's knowledge represents a rich fund which is of an advantage in a new design task. In literature we find many attempts trying to capture a designer's knowledge. However, most of these experiments were only done for concrete products. But they all proved that each case involves a huge amount of knowledge chunks which makes it difficult to capture the knowledge and to arrange its storage and management sensibly. Additionally, the knowledge is strongly characterized and influenced by its author. Although all experts agree that the valuable knowledge should be stored and kept ready for further exploitation there are no satisfying solutions to that problem yet; at least none which includes the designer's knowledge storing as well.

This knowledge can be articulated in the form of text fragments, plans or drawings, whereby the annotations may be recorded either in chronological order or according to sub-tasks. Every designer is aware of the fact that this more or less ordered collection of information may turn out to be very useful in future design projects. But many of the designer's activities are only done in his brain and are rarely formally documented, which means that part of the knowledge that evolves while working gets lost. Many designers, for example, associate different occasional knowledge sources with performed tasks or realized projects but never preserve this information.

As indicated above, every new design task is decisively guided by the engineer's experience, i.e. by the understanding he acquired in earlier works [Po04]. This fact does not only influence the knowledge itself but also the way the design process is arranged. Each design process can cause a new impulse which may become the basis for a new knowledge element. In general, the designer's knowledge is expressed in the following categories: activities, tasks, plans, knowledge sources. When a designer describes details of his works he uses representations which are specific for his domain. Consequently, there is a difference between describing the geometric modelling process of a car body or performing specific calculations. The most popular of all the categories mentioned above is the activity. Each activity has its sustaining knowledge sources. These knowledge sources evolve and as a result the activities evolve as well. The activities are employed to develop plans. At first glance the plan represents a number of activities which have to be carried out and which then evolve and undergo different stages of development in the course of the design process. But the plan also depicts the engineer's individual style of work and his actual state of knowledge. In most cases the designer remembers all the processes he went through, even though he has not taken notes.

When we want to store personal knowledge we have to keep in mind that explanations for different design decisions can be found in different components of the personal knowledge development in the past. In case the design process is the result of team work then the final design rationale can be found in different knowledge components belonging to different members.

As mentioned before, the knowledge background of a particular project often has a relatively complicated structure [Al06, AK06, Cl06, Mc04, NI04]. So when building a tool for the personal knowledge storage we should aim to represent the structure in the most reliable way. This also implies that we have to accept the diversity of knowledge representations. Under this condition the designer would be able to store his knowledge directly in its original computer form. The proposed computer tool should be permanently used by the designer – whether he is performing a design task or searching for suitable information from earlier projects.

2 Design Knowledge Modelling

The knowledge which is used in engineering design involves a relatively wide range of aspects starting form different domain areas, via their standards, used methods, organization topics to practical issues of implementation and also very personally developed components [Ma01, Po04]. Literature provides us with various attempts to categorize engineering knowledge. The main goal of these formalizations is to offer frameworks with which flexible environments for the storage and management of knowledge can be created. The categorization presented in [Ma01] is supposed to be a relatively complete one. It contains the following elements: terminology – set of terminologies used in a certain domain, specification of the project, 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.

The knowledge elements listed above are often integrated with different components of applied design process models. Mostly design process models are built as structures based on activities or sub-activities [Po03, Po04] (fig. 1). Each activity has knowledge as a background (fig. 2). Design knowledge is not static, it develops continuously. Every project can stimulate the designer to generate new knowledge chunks. The new knowledge chunks are not detached from the designer's already existing knowledge, as designers form mental links between the new knowledge chunks and the already existing knowledge components. This means the human designer stores the knowledge generated by him together with its links of associations in his brain. Repeating these knotting associations of the human brain in a computer model requires a lot of effort and time. And in spite of all it will never be complete. First, to make his knowledge "storable" for the computer the designer has to simplify and structure it. Consequently, the knowledge articulated in external forms – declarative or procedural representations - very rarely reflects the actual stage of the human designer in a particular case. Second, to really understand somebody's design decisions we would have to know all probable knowledge components which support it; a claim which can hardly be completely fulfilled. In real life it is often assumed that all the knowledge based explanations, called design rationale, are made for professionals with clearly defined competences. But clashes with other domains are always possible and misunderstandings cannot be excluded. Because of that, establishing knowledge based explanations for other domains is very time and labour intensive.

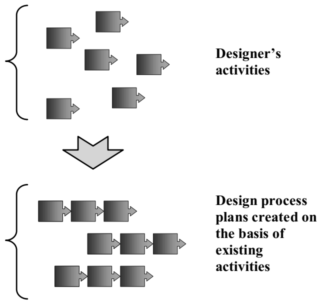

Figure 1: Activities used by designers and composed plans

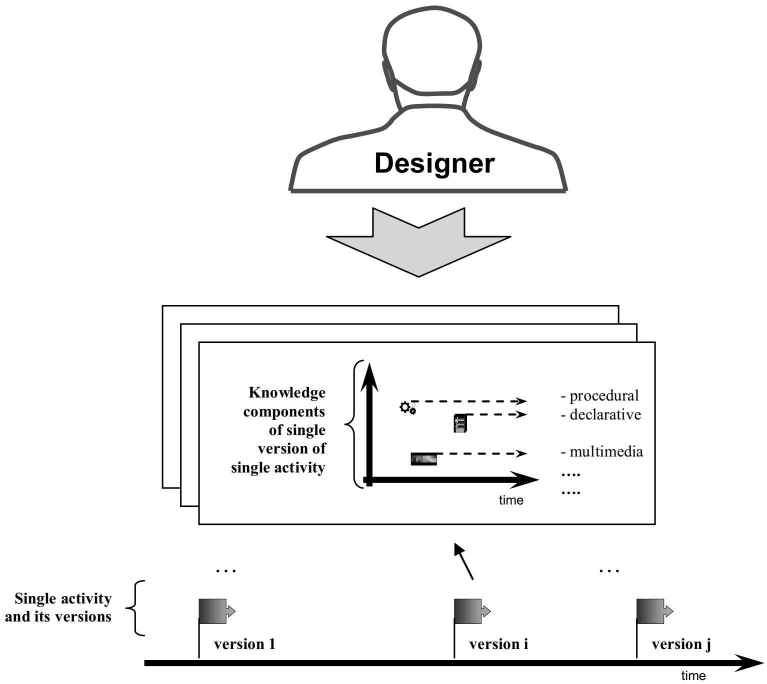

Figure 2: Single activity, its versions and components

Another important factor which influences the capturing of knowledge is the designer's willingness to define the knowledge design rationale of his design decisions [Po04]. As a rule the quality of the activities turns out to be relatively insufficient when the designer is committed to create a potential future knowledge source. The captured knowledge is often outdated or complicated in use. In those cases the knowledge depot works sometimes only as a port of enquiry. Instead of looking for the knowledge chunks the users search for the author of the knowledge in order to contact him and ask for clarification [Wa06].

Therefore the personal assistant - a kind of a personal professional diary realized in computer environment – seems to be a much better approach as it contains different knowledge chunks represented in a wide spectrum of computer representations. Most of the mechanical engineering designers with whom the author spoke or cooperated preferred activities as the basic form for describing design processes. Even after five or more years most creators of activities were still able to explain how they carried out a certain activity – a calculation, for instance. The designers could also describe their tools, knowledge sources, experiences etc. and often even remembered why and when they had changed the form of the calculations and their tools. Additionally, single engineers were able to tell which forms of activities were used in which project. Regarding these phenomena we come to distinguish two fundamental aspects of a personal assistant (fig. 3): personal assistant resources and project resources. The personal assistant resources imply activities and their knowledge background whereas the project documentations are stored in the project resources. The activities, strictly speaking their suitable respective components, should have connections to the projects in which they were used. The projects – via generated events – should have links to the components of the activities which were used in the design process. This kind of structure allows to analyse projects of the past and their knowledge background. Doing analysis the other way round is also possible. In this case it is possible to observe where certain components of activities were used and with what result.

Many practical computer implementations provide plans of design processes. The plans are composed of activities and sub-activities. When analysing realized projects it becomes obvious that the designers often depict their plans in a linear form (fig.4). But when designers speak about potentially realizable design processes then usually a kind of maze model is employed which permits all possible design paths (fig. 4). Obviously, for a designer and his knowledge a maze model - in other words a model of potentially realizable plans - is nothing static. It changes gradually according to the designer's knowledge development. So different valuable plans of the past - contained in the maze model - can also be stored in the designer's personal assistant environment.

After presenting the functionalities of the tools for the personal knowledge storage we want to consider the main goal of a personal assistant application. One of the basic assumptions is that the knowledge of the individual designer undergoes a kind of evolution. It changes from project to project but without losing its coherence.

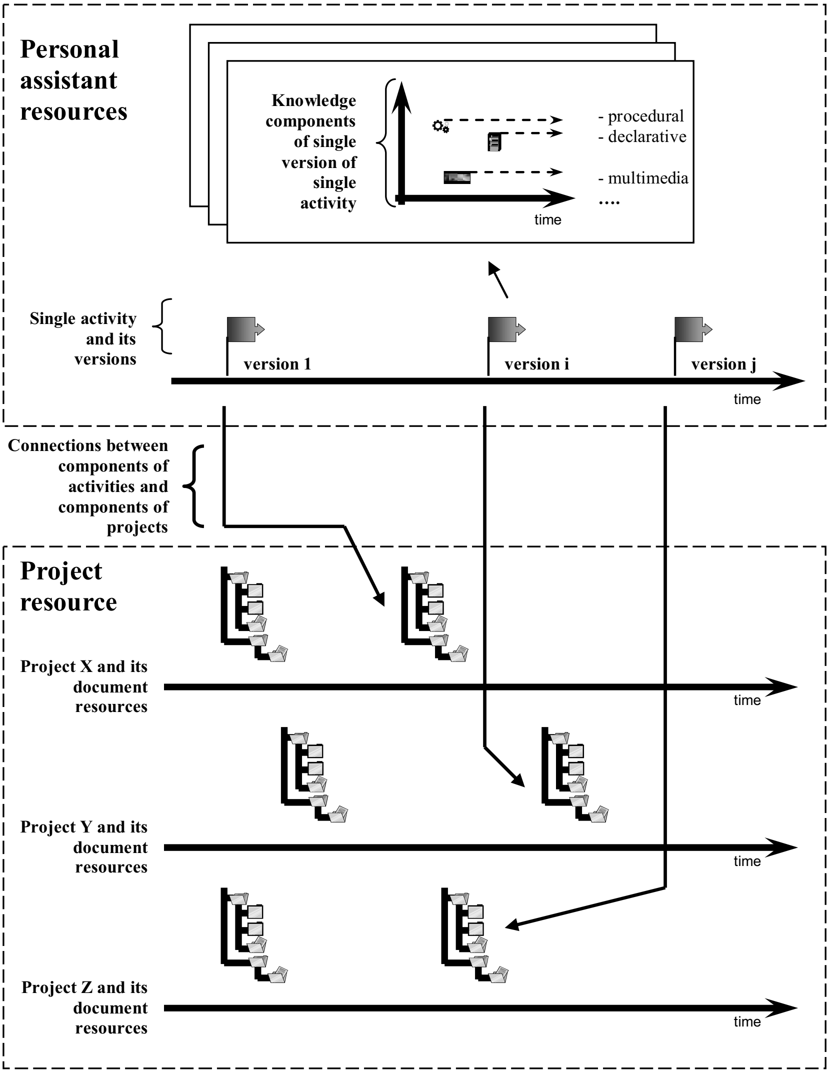

Figure 3: Personal assistant resources and their integration with project resources

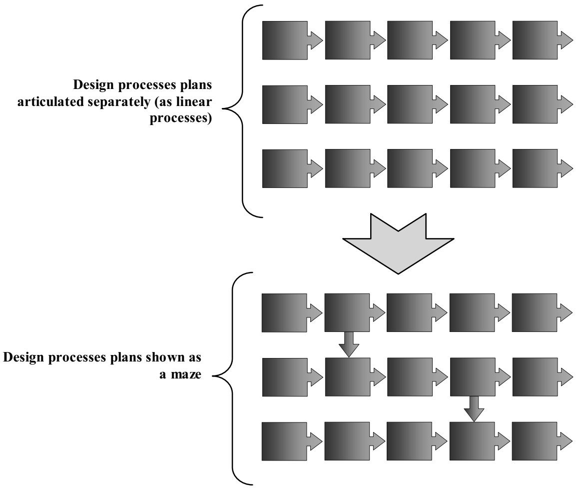

Figure 4: Linear and maze design process models

The knowledge stored in the personal assistant can be reused. Case Based Reasoning (CBR) [Po03] is one of the most suitable techniques for that purpose. In classical CBR the cases, i.e. the past solutions of problems are stored in the data base. When a designer has to solve a new problem he can search the data base for similar cases (fig. 5). Probably he will select the case which is most similar to the one he actually has to solve. After that the designer usually adapts the selected case to his actual problem and makes the application for it. Finally, the new case is stored in the data base of cases. With the presented approach of a personal assistant we can look for similar solutions in the past on the level of activities, sub-activities, their components as well as plans and projects or parts of them. It is relatively easy to build software on the basis of detailed similarity measures. When the measures have only an overall similarity, verification and tuning is difficult.

The above concept of a personal assistant is based on a specific structuring for engineering knowledge and on the Case Based Reasoning approach. But applications of other methods and techniques like blackboard architecture, data mining or multi-criteria optimisation [Po03, Po04] are also possible.

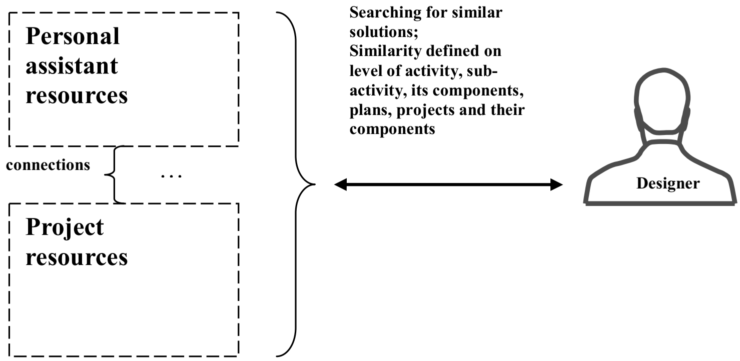

Figure 5: Searching for similar cases in assistant depot and in project depot

To represent the engineering knowledge of designers many different archetypes which are typical for certain domains can be used [Po04]. The author has met a big variety of real life design processes (for instance in geometric modelling or simulations) where knowledge was modelled with the help of very specific and unusual concepts. In the author's opinion these concepts should also be reflected in the structure of a personal assistant. It may have a very firm specific form then.

3. Verification and implementation

The author and his associates have been dealing over many years with the problem of modelling a designer's personal knowledge and the building of computer tools for its storage and management. The first basic concept and implementations were developed between 1995 and 2002. They were summed up in the book [Po04]. In 2005 the author, then together with Piotr Cichocki, took up that topic again.

Most of the concepts concerning a designer's personal assistant resulted from cooperation with professional designers. For more than twelve years the author also had lectures at postgraduate studies on computer aided design in machinery for people from industry. The subjects of the lectures were decision making in engineering and computer support. They were organized individually for different design processes. Through the observations made while working with the postgraduate students the author learned that design processes are done very individually and that the way of performing design processes cannot be generalized. Intensive studies of literature support the author's opinion.

During the first stage of developing personal assistant concepts (1995 – 2002) ten different applications and their computer implementations were built. They concerned the following domains [Po04]: car dynamics problems, supporting the design of a car braking system, supporting data analysis in an experimental aircraft chassis testing, supporting a heating system design for small houses and others. All the applications were developed on laboratory level and MS Visual Basic, MS C++, MS Access, MS Office, GBB, Clips were used as software tools and also different engineering systems. The user interfaces were built as multi-form applications. The aiding user navigation, however, was of little usefulness.

Although the tests proved the usefulness of this kind of software in general, several limitations became obvious as well. After a short contact with the software the users - this means at the same time the owners of the personal assistants – came to the conclusion that it would be best to have all personal resources (texts, software) and structures of their personal associations of the last 20 years stored digitally in their personal assistants. But it is not easy to transfer relatively large personal resources from non-computer media to a computer environment. The next problem is to acquire and store the personal structures of associations. Obviously, these activities can be partly automated. But the final decision lies with the owner of the personal assistant. The best results of implementing a personal assistant were achieved with either relatively simple or well structured problems.

Since 2005 the author has concentrated on the issue of how to widen the area for implementing the concept of the personal assistant. One direction of research aimed at a deeper integration of the present concept with existing engineering systems. The developed concepts and applications for that purpose concerned the following problems: production costs estimation [Bo05], explanation tools for Knowledge Based Engineering (KBE) applications [Po06a], automating the generation of information of the design rationale class [Po06b], integrating multi-criteria optimisation methods and tools for knowledge storing [PN05, PN06] and industrial fault analysis [PC07b]. The majority of these projects are still at laboratory level but compared to the application developed in the 90s they are much better integrated - nearly fully embedded - with the context models of a certain design problem and they involve important issues of the respective domains.

The issues concerning the application of the personal assistant in distributed environment are presented in the papers [PN06, Po06a]. The first example deals with the problem of multi-disciplinary optimisation where different sub-problems are modelled and controlled by persons who have specialized in different domains and who are not in physical closeness. The second example is meant to be for situations where a Knowledge Based Engineering (KBE) application is used by non-authors who do not work in the same place as its creator. The role of the application is to help to understand the functioning of a KBE application. The knowledge acquisition is performed on the basis of domain abstractions and not only on the level of application variables. The domain abstractions are then stored according to the dynamics of their development.

[PC07a] presents a new concept of a graphic interface of a designer's personal assistant. It is based on a so called "time line" and is similar to interfaces used in multimedia encyclopaedias but with the possibility to shorten the time axis dynamically. Figure 6 shows the concept of a personal assistant panel.

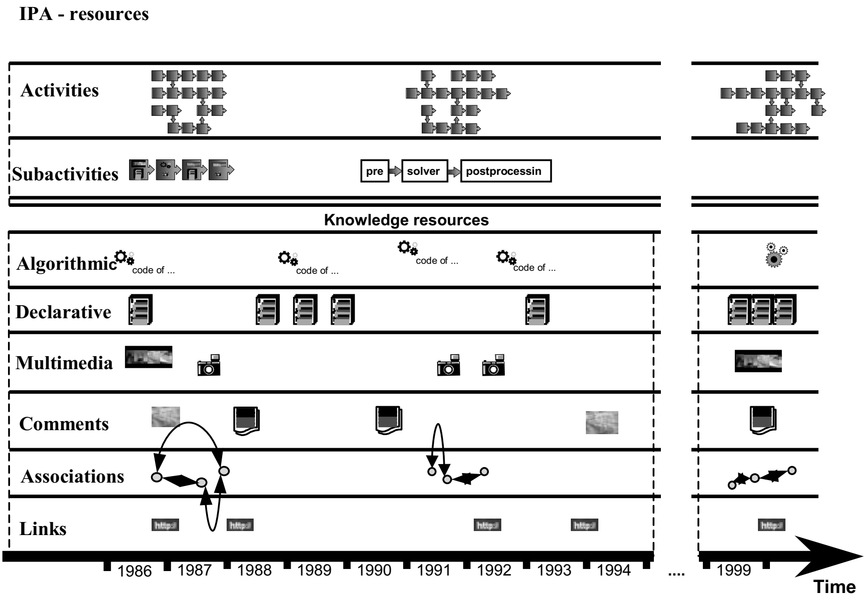

Figure 6: Concept of graphic interface of system

Apart from the interface, the application of new ontology based solutions [Da05, GR 94, Gu05, Ha06, Hi07, Ki06, Ki04, Ko06, KV06, Li06, Ya05a, Ya05b], methods and tools plays a very significant role in the implementation of a personal assistant. In fault diagnosis problems [PC07b] we tried to develop a module based on the ActiveKB system [Ac07].

4 Conclusion

The presented concept of an engineer's personal assistant is intended as a tool for an individual designer. It offers the possibility of collecting and storing knowledge and information which accumulates in the course of a designer's professional career. The developed concept tries to integrate project documentation, this means the results of an engineer's work, together with the engineer's tools which are based on both - his knowledge and experience.

The final goal of the concept is to reduce the effort needed for making design rationale notes. In the future the application is expected to store a relatively complete reflection of the engineer's knowledge and its evolutionary development. According to the author's experience the presented concepts and components are not necessary in all cases but they may serve as a kind of toolbox.

The already released implementations proved the practical usefulness of the whole approach. However, experiments on a wider industrial scale are still needed.

References

[Ac07] ActiveKB, http://www.interspire.com, 06.2007.

[Al06] Almefelt, L. et al.: Requirements management in practice: findings from empirical study in the automotive industry. Research in Engineering Design, 17, 2006; S.113-134.

[AK06] Aoyama K., Koga, T.: Supporting System for Design and Production with Sharing and Access of Product Failure. In: Leading the Web in Concurrent Engineering, IOS Press, 2006; S. 25-31.

[Bo05] Bonarowski, J. et al.: Engineering costing – industrial intelligent personal assistant context. 12th EG-ICE Workshop, Radziejowice, Poland, CD ed. by A. Borkowski, M. Schnellenbach-Held, 2005; S. 1-8.

[Cl06] Clarkson, J.: An Optimal Design Process for an Adequate Product? Design Methods for Practice, ed. R. Rohatyński, Zielona Góra, 2006; S. 21-26.

[CE05] Clarkson, J., Eckert, C. (ed.): Design Process Improvement. A review of current practice. Springer – Verlag, London, 2005.

[Da05] Davies, J. et al.: Next generation knowledge management. BT Technology Journal, Vol. 23, No 3, 2005; S. 125-160.

[GR94] Girratano, J., Riley, G.: Expert Systems Principles and Programming. PWS, Boston, 1994.

[Gu05] Gu, N. et al.: Ontology based semantic conflicts resolution in collaborative editing of design documents. Advanced Engineering Informatics 19, 2005; S. 103-111.

[Ha06] Hatamura, Y. (edit.): Decision – Making in Engineering Design. Springer-Verlag, 2006.

[Hi07] Higgison, S.: Your say: Personal knowledge management. Inside Knowledge, http://www.kmmagazine.com, (27.01.2007).

[Ki06] Kim, S. et al: Improving Document Accessibility Through Ontology-based Information Sharing. Proceedings of TMCE 2006, 2006; S. 923-933.

[KiT06] Kim, T. et al.: Multi-level modelling and access control for data sharing in collaborative design. Advanced Engineering Informatics 20, 2006; S. 47-57.

[Ki04] Kitamura, Y. et al.: Deployment of on ontological framework of functional design knowledge. Advanced Engineering Informatics 18, 2004; S. 115-127.

[Ko06] Koh, H., et al.: A method of accumulation and adaptation of design knowledge. Int. J. Adv. Manuf. Technol. 31, 2006; S. 421-433.

[KV06] Kotis, K., Vouros, G.A.: Human- centered ontology engineering: The HCOME methodology. Knowledge and Information Systems, 2006, 10; S. 109-131.

[Li06] Liu, S. et al.: A computational framework for retrieval of document fragments based on decomposition schemes in engineering information management. Advanced Engineering Informatics, 20, 2006; S. 401-413.

[Ma01] Managing Engineering Knowledge, MOKA - project. Professional Engineering Publishing Limited, London , 2001.

[Mc04] McMahon, C.A. et al.: A best practice advice system to support automotive engineering analysis processes. Engineering with Computers, 19, 4, 2004; S. 271-283.

[NI04] Nahm, Y., Ischikawa, H.: Integrated Product and Process Modeling for Collaborative Design Environment. Concurrent Engineering: Research and Applications, 12, 1, 2004; S. 5- 23.
[Po03] Pokojski, J. (ed.): Application of Case-Based Reasoning in Engineering Design. WNT, Warsaw, (in Polish), 2003.
[Po04] Pokojski, J.: IPA (Intelligent Personal Assistant) – Concepts and Applications in Engineering. Springer-Verlag, London, 2004.
[Po06a] Pokojski, J.: Knowledge Based Engineering and Intelligent Personal Assistant Context in Distributed Design. In: Intelligent Computing in Engineering and Architecture, LNAI 4200, Springer-Verlag, 2006; S. 519-528.
[Po06b] Pokojski, J.: Intelligent Personal Assistant as Source of Design Rationale Information. Proceedings of The Sixth International Symposium on Tools and Methods of Competitive Engineering – TMCE 2006, Ljubljana, Slovenia, CD, 2006; S. 1-10.
[PC07a] Pokojski, J., Cichocki, P.: Personal Knowledge Structuring – Issues, Concepts and Applications in Engineering. Proceedings, ProSTEP Science Days 2007, Bremen, (it will appear), 2007; S. 1-10.
[PC07b] Pokojski, J., Cichocki, P.: Intelligent Personal Assistant Concept in the Context of Fault Analysis. AI Meth 2007, Gliwice, 2007 (it will appear); S. 1-10.
[PN05] Pokojski, J., Niedziółka, K.: Transmission system design – intelligent personal assistant and multi-criteria support. In: Next Generation Concurrent Engineering – CE 2005, ed. by M. Sobolewski, P. Ghodous, Int. Society of Productivity Enhancement, NY, 2005; S. 455-460.
[PN06] Pokojski, J., Niedziółka, K.: Transmission System Design – Decisions, Multi-Criteria Optimization in Distributed Environment. In: Leading the WEB in Concurrent Engineering, Next Generation Concurrent Engineering, IOS Press, Frontiers in Artificial Intelligence and Applications, Vol. 143, 2006; S. 595-602.
[Re01] Regli, W. et al.: A Survey of Design Rationale Systems: Approaches, Representation, Capture and Retrieval. Engineering with Computers, 16, 2001; S. 209-235.
[Ya05a] Yang, M.C. et al.: Design information retrieval: a thesauri-based approach for reuse of informal design information. Engineering with Computers, 21, 2005; S. 177-192.
[Ya05b] Yang, Q.Z. et al.: Configurable Product Design Processes with Integrated Knowledge Maps. Next Generation Concurrent Engineering, International Society for Productivity Enhancement, Inc., NY, 2005; S. 161-166.
[Ul02] Ullman, D.G.: The Mechanical Design Process, McGraw-Hill (Third Edition), 2002.
[Wa06] Wallace, K.: How engineering designers retrieve information. Design Methods for Practice, ed. R. Rohatyński, Zielona Góra, 2006; S. 171-180.