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Knowledge Based Processes in the Context of Conceptual Design

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Abstract. The paper presents an attempt of real, industrial, engineering knowledge modeling, used in a small company. The authors concentrate on the concept of personal/team knowledge repositories and tools which can support conceptual design. The introduced software solutions allow to perform and acquire key steps which are necessary to achieve the final conceptual goals.

Keywords. Engineering knowledge modelling, conceptual design, case study

Introduction

The paper presents an attempt of real, industrial, engineering knowledge modeling, used in a small enterprise. The authors focus concentrates on the stage of the conceptual design [1][2]. The developed software solutions allow to acquire key steps which are necessary to achieve the final conceptual goals. Both modelled and analysed design processes aim at capturing design steps based on mental as well as formal modeling.

Usually, the performing of engineering design tasks concentrates on two types of activities [3][4][5]:

- activities connected with modelling the reality,
- activities analysing the models of reality and associated decision making actions.

Both types of activities are normally fulfiled and integrated by the designers [6][7][8][9][10]. In doing so, the applied models can be on different levels of complexity, starting from very simple ones, which are based on few formulae to huge systems of equations. Problems of a high degree of complexity are mostly solved in collaboration with other designers [3][4][7][8][9][10]. But both complex problems and simpler ones are first of all “solved” in the engineers’ minds and hardly ever recorded in one way or other [5].

All activities mentioned above require engineering knowledge which is the result of education and professional experience [5][11][12].

Although designers’ knowledge can be stored in different forms of computer representations it is difficult to express all details connected with a particular set of engineering problems [5][13][14][15][16][17]. Only the designer as the main knowledge source understands everything widely, this means the multi-aspect and multi-context of the problem [5].

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The designer is able to operate actively with his knowledge [5][13][14][11]. The knowledge can be the result of reflection on past tasks which he recalls [19][20][21]. In many cases, especially in conceptual design, this is a kind of evolutionary progress in a selected knowledge development.

In the paper we concentrate on the concept of personal/team knowledge repositories and tools which can support conceptual design. The whole approach was created and verified in a real industrial design office [22].

1. Design knowledge modeling during the conceptual stage of a design process

Each design process is determined by the final function of the respective product [1][2]. For the design knowledge modeling the product function is decomposed on sub-functions [23]. Designers look for suitable and feasible solutions to realize particular sub-functions. Then the alternate combinations of the analyzed solutions are examined and evaluated. The new approach is repeatedly corrected till the final satisfying solution is achieved.

In the literature we find various methodical approaches for conceptual design [1][2][24]. One of the most interesting ideas seems to be the so called systems engineering [25]. This approach bases on the assumption that there are certain components with their attributes and relations, etc. which could be used in formal model building [26]. The complexes of such elements can be used to model the structures and functions of a product for example [27][28][29]. Applying this approach may important characteristics of a product can be preciously captured [30]. The main goal is to shift the development process from a document-centric to a model-centric one [31].

Solutions based on the above concepts offer better quality of knowledge storage. Moreover they represent a better discussion basis for the team members.

On the other hand these approaches require more effort from the designer's side.

To build new versions of the existing systems' engineering models or to create their thematic libraries are tools which may be helpful [32][33].

The concepts developed during conceptual design can first be expresed in the form of the initial paper document. Later evolutions can be moved to the environments with systems' engineering computer models.

More than 20 years ago people started to use multi-media records for knowledge storing [3][4][7][10][34]. Documents/logs of communication between the designers (team members) about the conceptual design stage became a valuable material. The recorded information was not a mere collection of sentences. The recordings contained descriptions, opinions, models and acts of validation. Sometimes even interactions between team members together with their argumentation could be found [19][20][35][36][37].

Looking at the conceptual design from a more general perspective we can observe two kinds of activities [24][38][39][40]:

1) team discussions, interactions between team members,

2) individual work of team members together with their own concepts, models and tools.

These two types of actions are usually performed one after the other. Then the proceedings start again from the beginning and are repeated in a number of cycles. We can try to apply computer tools for both types of actions. With the first type we can record acts of communication, store argumentation (design rationale), explain decision making processes, etc [41]. With the second type we can store models typical for different domains – for instance those belonging to the systems' engineering category.

The proposed concept of the knowledge storage during conceptual design in a team offers the chance to catch core information associated with the whole process together with its key details, decisions and applied strategies.

Many papers concerning conceptual design are based on design problems which are especially created for the purposes of a certain research [5][18][42][43][44].

In the paper the authors present the analysis of the conceptual phase on the example of steel sheet metal processing machines in a small enterprise [22]. The authors try to provide an architecture of the computer system and attempt to implement a more universal, multi-profile, multi knowledge representation tool that is able to support the designers with solving the problems mentioned above. The results of the analysis of the selected real design processes, their knowledge background with their conceptual design stages are presented in the article [22]. This material is the basis for the solutions shown in this paper. In the next chapters the concepts of the computer environment for conceptual design support are explained.

2. Exemplary environment for conceptual design support

In industrial practice tasks belonging to the considered class of conceptual design problems are usually solved in an iterative way [24][22]. The degree of requirements, and design details increase gradually over time as the result of systematic problems' modeling and collaborative team work.

In the subject company mentioned above the concept creation of a new machine looks like one conceptual design task.

The case study design team consisted of 8 persons. The task referred to the problem of a multi-stage manufacturing process of a steel sheet metal processing machine. The first version was in principle a further development of the existing machine to which new components were added "by hand". The result was approved as a first iteration of the process. The concept was evaluated and validated and its development was accompanied by very detailed and comprehensive discussions. The team members came to the conclusion that several partial concepts and solutions should be improved. The improvement led to a set of new partial solutions. After that the designers started to work individually or in two persons teams. While looking for the partial detailed solutions they used their personal/team models and tools. Additionally series of carefully planned experiments were performed.

The activities described above were treated as one cycle. Although there existed 7 cycles altogether. During this stage different available knowledge resources and the tools associated with them were applied.

For the process structure described above the authors have built a more formal and computer based approach to create a new manufacturing machine. In the proposed approach the specificity of the domain plays a significant role. The problem was structured in the following manner: **production line, system, sub-system, part, knowledge element.** This structure reflects the way the designers look at the whole machine.

The **knowledge elements** of the above approach had the following forms:

- computation modules (different programming tools, different sizes and complexities),
- design recommendations (useful hints, design rules),
- standards (documents),
- past project documentation,
- multimedia recordings from previous projects (discussions, records of collaborative sessions).

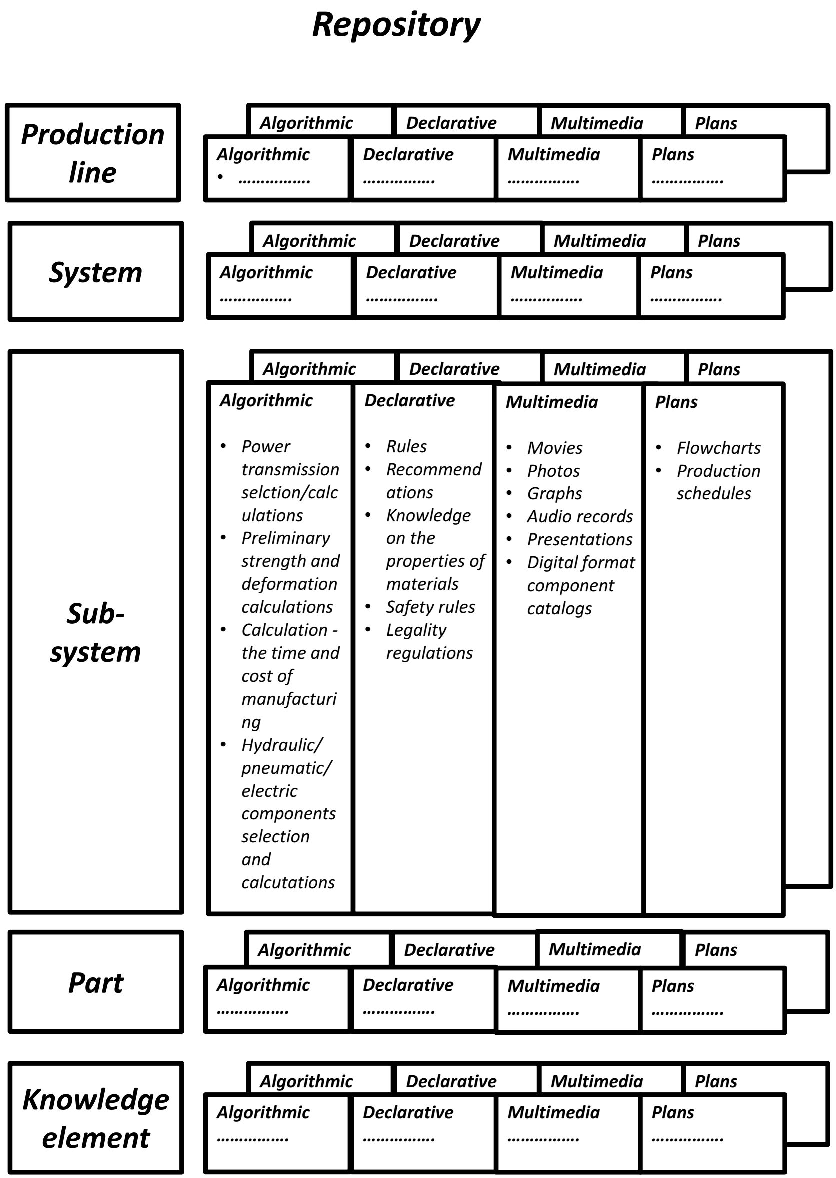

Figure 1. Knowledge repository and its structuring.

The **Parts** contain sets of knowledge elements which are strongly connected with the respective part. The **Sub-systems** store knowledge how to design certain mechanisms, bodies, geometric features of rolls and transmissions, control systems, etc.

The **Systems** and **Sub-systems** store knowledge of the devices which are main parts of the production line. The **Production lines** keep knowledge about requirements and knowledge connected with the manufacturing processes performed on those lines.

An exemplary content of the repository with its structuring is presented in Figure 1.

The problem of the conceptual design for the main structure of the approach, as it was performed in a specific company is shown in Figure 2. The diagram shows the core elements of the conducted processes with their descriptions and visualizations.

Figure 3 shows the structure of the computer environment for the conceptual design support of the new developed approach. The concept of the environment was created after analyzing a number of real-life conceptual design processes. However, the

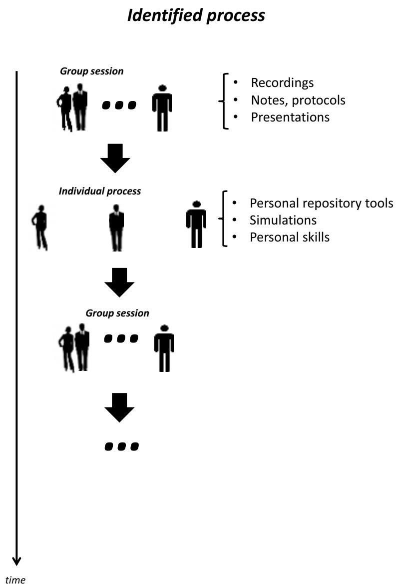

Figure 2. Structure of identified conceptual design process.

concept is not universal. It may only function as an actual iteration of the developed environment. Looking at its software it reminds a toolbox with useful solutions. While operating with the environment the user can exploit resources from the structured repository and build his own structure of activities based on the scheme presented in Figure 3. Figure 4 depicts two scenarios of actions performed during two different projects.

3. Implementation

The authors have also started working on the implementation of the proposed solution. They assumed that the new environment consists of a user interface (similar to the actually developed for smartphone applications) and a tool controlling the functionalities which were realized with the software applications originally used in the company. The concept of the user interface is similar to the ideas shown in Figures 1-4.

The interoperability of the available applications and repositories was ensured by wrapping which is similar to the techniques used in multi-disciplinary optimization. The data integration was solved individually for particular functionalities.

The authors have tried to develop their applications in two versions (using an object oriented approach): 1) strong in reflecting the reality of the mentioned company, 2) using more general and universal solutions.

The newly created system is currently being tested, corrected and verified in the subject company. Sets of the developed modules are used as a support in sub-sequences of actions in exemplary problem solving. Figures 5 and 6 show the computer interface and one of the exemplary problems.

Two of the authors are very deeply involved in the implementation process. Jarosław Pruszyński, apart of the working on the method and software development, is the proffesional leader of the design team (in subject company) which tests and verifies the proposed software solutions. The subject company is involved in the construction and manufacturing of the equipment as well as in the complete customizable production lines according to customer needs. The specificity of the company is that practically every order can be produced in only one copy, hence the problems of designing and starting machines are very well known to him.

Konrad Oleksiński, who also works on the method and software, is responsible for implementing and maintaining software and hardware in a large media company. He also manages the process of creating and implementing new applications used in the company's business.

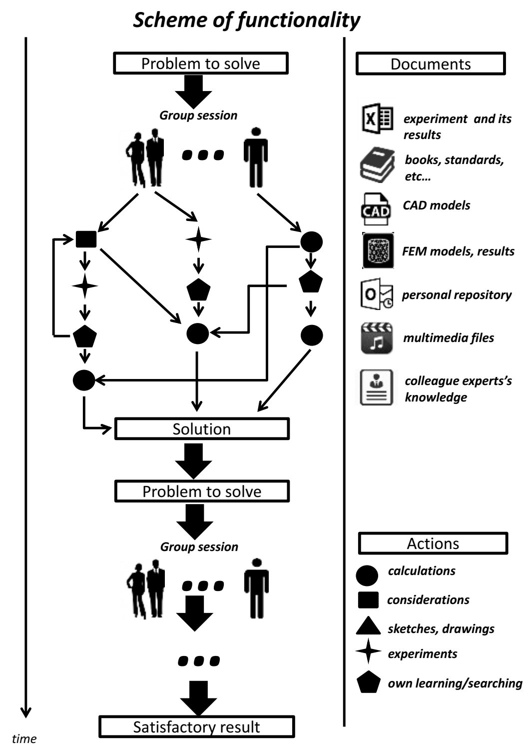

Figure 3. Backbone of modeled conceptual design process.

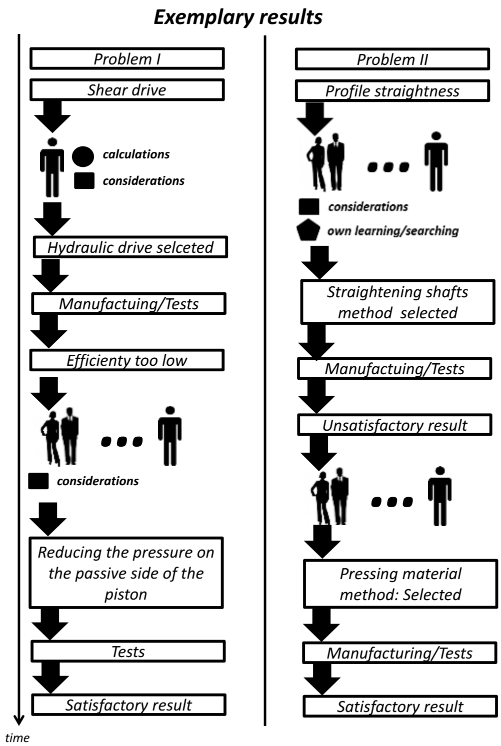

Figure 4. Two exemplary instances of performed conceptual design scenarios.

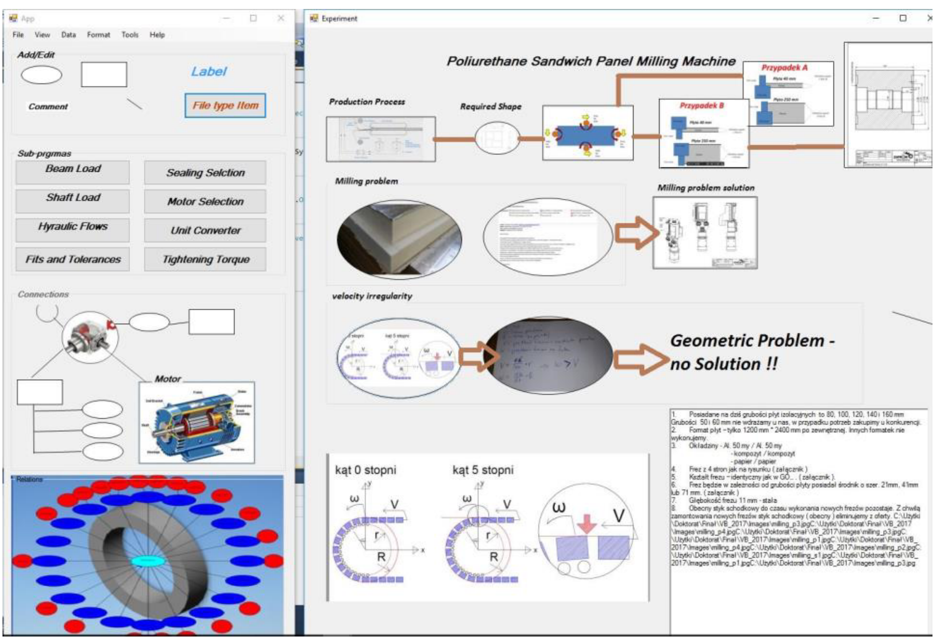

Figure 5. Snapshots of the developed application – searching for analogies (arrows indicate the order of the performed actions).

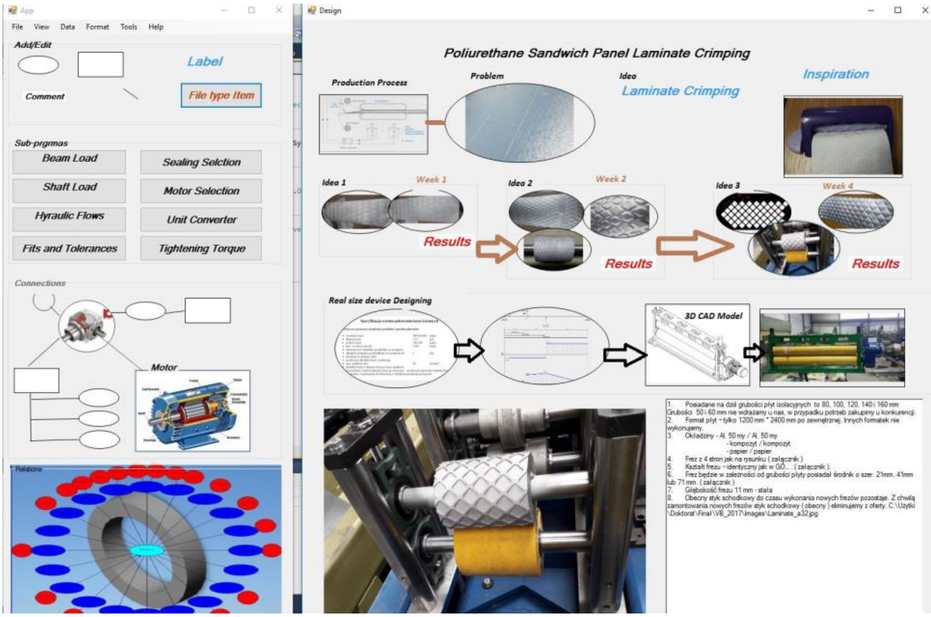

Figure 6. Snapshots of the developed application – succesful solutions (arrows indicate the order of the performed actions).

4. Conclusions

The paper presents a proposal for the computer support in conceptual design. The proposal is based on a real-life case study and it was created with the intention to a high degree of flexibility.

The whole approach is based on many human-computer interactions. The analyzed cases indicate that the considered class of problems needs many knowledge sources and the speed of processing is less important. The open format of data exchange seems to be useful in this case.

The performed research allows to formulate several detailed remarks:

1) During the process of creating the new conceptual solution it was very important to store the following information:

- new ideas, presentation of new concepts, acts of communication, models and their descriptions,
- information about models which had been used earlier and were re-applied in the next design iterations, information how to operate with these models, how to select the values of their parameters and how to make their structural modifications,
- descriptions, characteristics of the sequences of the experiences which were realized and corrected during the concept development (together with elements of qualitative reasoning),
- information about human sessions and their results (also that sessions realized out of the project plan),

- information concerning the solutions of alternative variants which influenced the finally selected ideas,
- information concerning: a) new ideas and their authorship, b) the form in which these new ideas were realized in practice.
- information about the evolution of the concepts during the design process from the personal and team perspective.

2) Each team member had the chance to present his new ideas. In the end all new exposed ideas were stored.
3) Small firms suffer specifically from permanent market pressure. This fact strongly compels entrepreneurs and engineers to develop new conceptual solutions and also requires approaches like the one prepared in this paper.

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