

## **CONTENT-BASED DESIGN ENGINEERING THOUGHT RESEARCH AT OULU UNIVERSITY**

Kalevi Nevala and Jouko Karhunen

In memoriam Professor Uolevi Konttinen 1912 - 2004

*Keywords: Engineering design, engineering education, thought research.*

### **1. Introduction**

Thinking is the ultimate tool in engineering design. In spite of all technical support, the ideas are generated and major decisions made by human mind. This fact has been recognized in the Laboratory of Machine Design at Oulu University, Finland, since the start of the Laboratory in late 1960s.

The founder of the Laboratory, Professor *Uolevi Konttinen*, had a comprehensive 30 years experience in recruiting and supervising engineering designers and researchers, when he was called up to Oulu University in 1968. Since 1938 he had piloted the engineering design department of Valmet Rautpohja Works from a drawing office of a couple of people to the R&D unit of over 350 persons, and meanwhile contributed to the engineering education in Finland in many ways.

The Laboratory of Machine Design at Oulu University was the first one in Finland introducing officially the topics of creative problem solving to the curriculum of higher engineering education. In 1970s the topics of creativity were primarily based on pragmatic American literature, especially on the work of Alex Osborne [Osborne 1979] and his colleagues and followers. The methods introduced in this literature, like Brainstorming and Synectics, have been popular and in appropriate cases also effective, but they lack sound scientific basis.

Konttinen's philosophy was to balance creativity and systematics in the thought processes of the designing engineers. The seminal work of Gerhard Pahl and Wolfgang Beitz [Pahl et al. 2003] as well as the work of other researchers of so called German school inspired the work in the Laboratory from the beginning of 1970s. After his active career Konttinen translated Pahl & Beitz's *Konstruktionslehre* in Finnish in late 1980s.

Konttinen lit the spark of creativity in many year classes of engineers.

The authors of this paper were among the first students of Konttinen at Oulu University. Jouko Karhunen is the current professor of engineering design in the Laboratory of Machine Design at Oulu University since 2000. Kalevi Nevala worked with Konttinen from the very beginning up to the early 1980s; as his assistant and time to time as a deputy chair holder.

Konttinen's successor professor *Jorma Tuomaala*, the chair holder from 1982 to 1999, continued the human centered tradition on slightly different grounds. During the years of his professorship he composed an impressive phenomenological description of the thinking process of an experienced engineering designer [Tuomaala 1999; available from the web site of Oulu University: URL <http://herkules.oulu.fi/isbn951425130X/>].

In the beginning of year 2003 the authors of this paper launched a research project named *Human Cognition in Engineering Design*, in collaboration with the Cognitive Science of Jyväskylä University, Professor Pertti Saariluoma and the paper machine manufacturer Metso Paper Inc., Vice President Mikko Karvinen. In the beginning of 2004 the project was renamed to the research program on the *Content-Based Design Engineering Thought Research*.

In this paper we will put forward a brief summary of the objectives and the current state of our thought research on engineering design; honoring the memory of Professor Uolevi Konttinen, who sowed the seeds three decades ago. Our goal is to establish a continuing research program, which produces new material for the basic education of engineering design and enables postgraduate studies and researcher training on the subject area. The progress of the research project can be traced from <http://cc.oulu.fi/~nevala/>.

## **2. Content-Based Design Engineering Thought Research**

The basic idea of our approach to the thought research on engineering design is that the knowledge content of the object domain affects essentially on the structure and outcome of the thinking process [Saariluoma 1995, Nevala in press].

The empirical material from our current case study in the paper machine manufacturing industry demonstrates clearly how the globally shared knowledge content of papermaking sets rather distinct constraints and boundaries for the ways how the experienced designing engineers represent the design assignment to themselves – that is, how they form the *mental representations* of the design assignment and its details.

Traditionally the research on thinking and creativity has been focused to the capacity restrictions of human mind. It has been like studying the properties of the container instead of the contents of the vessel. We all have fairly equal brain facilities for thinking. What distinguishes us from other people is the content of our thoughts. For this reason we believe that the content-based approach to design engineering thinking can reveal new aspects of the design process [Nevala in press].

### **2.1 Theoretical framework**

The theoretical framework is based on the principles of the content-based cognitive psychology [Saariluoma 1995]; adjusted to fit in the engineering design [Nevala in press]. Professor Pertti Saariluoma developed the scientifically innovative conceptual system of the content-based thought research in the context of research on Chess players' thinking, but it can be utilized in more complex problem solving situations, like in engineering design, as well [Saariluoma 1995, Nevala in press].

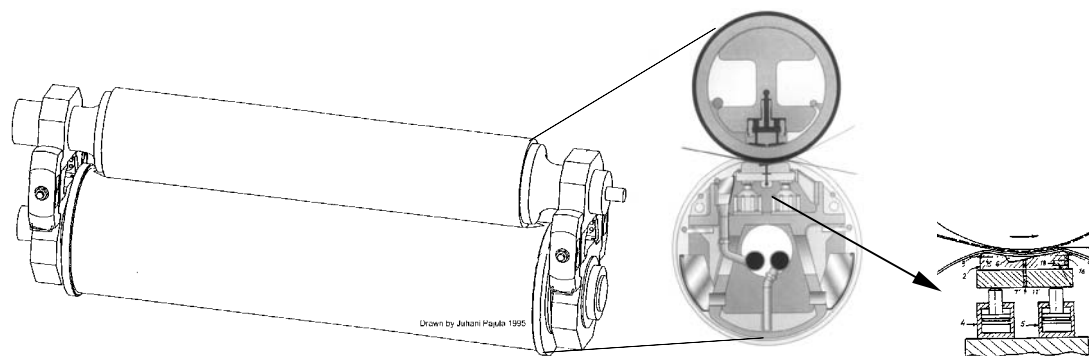
The scientific exploration of the content-based thought processes in engineering design entails defining a context-specific conceptual system of the basic notions. For example, the *knowledge content, functional rules and constraints* of the object domain; the *mental representations and thought models* of the designing engineers; the *mental spaces* or the *scope* of their thinking; how do the content-specific features of the object domain affect the process of *apperception*, that is, the process of “*seeing*” *things as something*; how do the processes of *restructuring the mental representations* proceed in the *reflective* and

*constructive* modes of thinking; how are the *consistency and sensefulness* of the mental representations composed in the minds of the designers; etc.

Many of these concepts are familiar from the theories of cognitive science, but some have been invented and redefined specially for the content-based psychology [Saariluoma 1995]. Kalevi Nevala will provide the context-specific definitions and the basic analysis of these central notions pertaining to a case study in paper machine design in his shortly out coming monograph [Nevala in press].

## 2.2 Domain of the empirical investigation

As the domain of our case study we chose a major breakthrough in the paper and board making technology, namely, the emergence of the extended nip press ENP (Fig.1.); first in 1980s to the board making machines, and later on in 1990s also for the paper machines.



**Figure 1. A modern extended nip press (ENP) for paper machines**

ENP provides a wider contact zone, i.e. the nip between two rolls and consequently a longer press impulse on the fast running paper web. The lower roll has a flexible mantle, which is pressed by the upper roll against a contoured “press shoe” inside the lower roll.

The idea of extending the water removal impulse in the press units of paper machines is an old and actually a very natural proposition, but the technological prerequisites in realizing a reliable construction were supposed to be lacking up to the beginning of 1980s. But when the American company Beloit in collaboration with the belt producer Albany delivered 1981 the first “shoe press” to a board making machine in Springfield, USA, the other paper and board machine producers were alerted.

Valmet Paper Machines (now Metso Paper Inc.) started several projects in order to investigate the possibilities of realizing the ENP.

## 2.3 Practical realization of our design thinking research

### 2.3.1 Interviews

We had a possibility to interview the engineers who actually designed the mechanical constructions enabling this technological breakthrough at Valmet Paper Machines / Metso Paper Inc. This multi-phased development process took about 15 years to reach the current established status in the late 1990s, and is, of course, progressing all the time.

The basic tool of our methodology is the *reconstructive modelling* of the actual development process. From the beginning of 2003 we held several group interview meetings with the experts of Metso Paper Inc. On the basis of these discussions we then made an overall

description, a *reconstructive model*, of the development process as a whole, and used it as a framework for the iterative individual interviews and detailed document analysis.

The detailed interviews were carried out from June 2003 to August 2004. Several engineers of mechanical engineering background were interviewed. They had participated in the actual development process on different levels of Valmet/Metso organization and in different phases of the design work; from the corporate level product planning, through the sales department, up to the actual product development on several levels of details.

The interviews were repeated one to four times, depending on the need for supplementary information. Furthermore, several focused questions were asked by phone and email. This iterative information gathering method provided us with a fragmentary but representative picture of the complicated process of the ENP development.

### **2.3.2 Document analysis**

The interviews were complemented by a rather thorough document analysis. Nearly hundred patent publications were analyzed and a representative set of the organizational material was scrutinized.

The interviewees used actively the applicable drawings and other data in illustrating the progress of their ideas during the development process. The documents helped the engineers to recall, what they had been thinking, when the actual design process was going on. Furthermore, the organizational documents allowed the researchers to cross-check the interview material.

Synthesizing the interviews and documentary material we call the method of *active reconstruction*.

## **2.4 Results**

The first results from this investigation will be published shortly as a monograph [Nevala, in press] and later on also as papers in appropriate magazines. The gathered material allows also further research and several publications utilizing our *reconstructive model* as a framework. Here we will present only a brief summary of some ideas which came up in our analysis.

On the basis of the empirical material we concluded that there is a three phased basic cycle in design engineering thinking, namely, (1) *apperception*; "seeing" things as something, (2) *reflection*; restructuring the apperceptive mental representations, and (3) *construction*; integrating the appropriate sub-solutions to a working whole. This basic procedure can be called ARC-cycle.

Apperception seems to be the key element in explaining the content-based logic of design thinking. The administration of the substance knowledge is essential in order to "see" an object correctly, as the design assignment requires.

In order to understand the actual flow of design thinking it is necessary to remember the restricted capacity of human working memory [Miller 1956]. Thinking must be focused on a rather narrow area at a time. This necessitates changing the focus and perspective of thinking during a large design process. The designer must concentrate on one detail at one time, but the total situation, with all its intricacies, must be kept in mind as well. All details and the totality must be adjusted together within the same process. This leads to an iterative process; from the constraints and boundaries of the problem to the overall layout concept and finally to the cyclic refinement of the details.

Our empirical material shows very neatly how the ARC-cycle is employed on several levels of design thinking; from contouring the details of the “press shoe” to composing the total press section for a paper machine.

Another major finding is that the prerequisites of design thinking are very strongly socially, even globally shared. The realities of the papermaking science and industry dictate the rules and boundaries of paper machine design. Nearly all fresh product development engineers propose radical improvements in papermaking. But when they get themselves acquainted with the three basic requisites of papermaking the alternatives diminish.

According to our empirical material these three conditions, which must be fulfilled concurrently in all constructions of paper machines, are: (1) the required properties of the paper must be achieved, (2) the runnability of the paper machine must be high and (3) the construction must be machine technically possible. If one of these provisions fail, the proposed innovation is not practicable.

There are both positive and negative inflictions caused by the shared knowledge content – presumably in all professions. The very essence of the expertise is embedded in the shared knowledge contents. But gripping firmly on the traditions means a definite dead end of the business, like the downfall of the American Beloit Corporation demonstrates.

### **3. Discussion**

The educational achievements in the human centred approach to engineering design at Oulu University have been significant. The spirit of creativity, which was planted by professor Konttinen in 1970s, has survived and flourished. The graduates from Oulu University have had brisk demand in industry.

Paradoxically, the research on the human related subjects has been minimal. An obvious reason for this is that thought research and the engineering topics have been traditionally rather remote areas of scientific research. Thought research is difficult, even to the specialists, due to the unconscious and tacit elements of thinking. The scientific approach to design thinking research, solely on engineering basis, is very difficult. Multidisciplinary efforts are necessary.

The authors of this paper have now got a possibility to refine the experiences of the last three decades and to start planning a research program in collaboration with the Cognitive Science of Jyväskylä University and the paper machine manufacturer Metso Paper Inc. The eventual objective is to convert the human centered tradition of our Laboratory from the pragmatic level to a scientific research program, which enables a continual postgraduate education on the field of design engineering thought research.

One major difficulty in the scientific formulation of the engineering design process has been the fact that the fields of design are so diverse. All design processes have, of course, some universal properties. However, when looking at the design process on a general level the details fade away.

The knowledge content of paper machine manufacturing is definitely different from that of the producer of microelectronics – structurally and on substance basis. In order to capture the content-based logic of the design assignment it is necessary to administer the substance knowledge.

The content-based approach to the engineering thinking is rather laborious. Capturing the actual contents of an industrial design engineering process is very difficult. Online monitoring

of a long ranged development process is impossible. That is why we have utilized the reconstructive approach.

Our empirical material raises several questions.

Is it really necessary to spend a six to seven years period in developing a major improvement in paper machine technology? Would it be possible to expedite and intensify the product development by loosening the globally shared conservative thought models? The product development engineers are undoubtedly very creative and effective. Would it be possible to direct their creativity more effectively by understanding the prerequisites of design thinking?

We think that SIG-AEDS is the right forum for discussing these topics in the future.

## References

- Miller, G. A., "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information", *Psychology Review* 63, 1956, pp 81-97.
- Nevala, K., "Content Analysis of an Industrial Design Engineering Thought Process. An Inside View on the Emergence of the Extended Nip Press in Paper and Board Machines 1983 – 2003", *Jyväskylä: Jyväskylä Studies in Computing*, in press.
- Osborn, A. F., "Applied Imagination". New York: Charles Scribner's Sons, 1979.
- Pahl, G., Beitz, W., Feldhusen, J., Grote, K. H., "Konstruktionslehre. Grundlagen erfolgreicher Produktentwicklung. Methoden und Anwendung", Berlin, Springer, 2003.
- Saariluoma, P., "Chess players' thinking", London, Routledge, 1995.
- Tuomaala, J., "Creative Engineering Design", Oulu: Oulu University Press, 1999.

Kalevi Nevala  
Laboratory of Machine Design,  
University of Oulu  
Box 4200  
90014 Oulun yliopisto  
Finland  
[Kalevi.Nevala@oulu.fi](mailto:Kalevi.Nevala@oulu.fi)  
+358-40-7736551