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SUPPORTING DESIGN BY MEANS OF MORPHOLOGICAL OVERVIEWS AND C-K THEORY IN THE BUILT ENVIRONMENT

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1. Introduction

In contemporary architecture an increasing emphasis on performance aspects like energy consumption and sustainability leads to an increased complexity. This complexity makes it necessary to involve designers from other disciples than architecture, like structural engineering, building physics and building services, earlier in the design process. The most important decisions of a building design project are taken early in the design process in the conceptual phase.
The unsatisfactory cooperation between building design disciplines has resulted in calls for better organization of the design process [Wichers Hoeth and Fleuren, 2001]. In this context, traditional approaches to organize and plan these complex processes may no longer suffice [Van Aken, 2005].
Getting a better understanding of how to improve the knowledge exchange within the design team's process is essential to adequately support design teams in the conceptual design phase. This research set out to develop a tool that would make it possible to better organize knowledge within the building design team and thereby improve the exchange domain specific design knowledge from the outset of the conceptual design phase.
Generally speaking, design is a creative process based on the transformation of needs into solutions. In this process existing knowledge and information about the actual needs of the principle forms the basis to work from. Following [Dorst, 1997], it is commonly accepted that design can be generally represented by two design paradigms: design as rational problem solving [Simon 1969]; and design as reflective practice [Schön, 1983].
The development of rational methods grew/evolved into the Design Methodology movement of the 1960's [Cross, 2001], culminating as far as architecture is concerned, in the early work of Christopher Alexander. However Alexander's work was seen by architects as definitive proof that a rational problem solving approach was not suitable for design. This belief substantially influenced architectural education. In his own words, Alexander postulated that "There is so little in what is called 'design methods' that has anything useful to say about how to design buildings that I never even read the literature anymore... I would say forget it, forget the whole thing…" [Alexander, 1971]. Subsequently, intuitive and artistic approaches were preferred over methodical and systematic ones. The direction that schools of architecture, as most other design schools, are still following is best described by representing designers as reflective practitioners [Schön, 1983]. Reflective practice theory involves thoughtfully considering one's own experiences in applying knowledge to practice while being coached by professionals in the discipline: "*in 'reflective conversation with situation' designers work by naming the relevant factors in the situation, framing a problem in a certain way, making moves toward a solution and evaluating those moves*" [Dorst, 1997, p.67].
In contrast to approaches in architecture, after the 1970's rational problem solving paradigm continued to provide the background for the development of process-oriented approaches in Engineering. A

number of engineering design process models were created, various overviews and comparisons of which can be found throughout the literature [Bayazit, 2004, Wynn & Clarkson, 2005, Cross, 2007, Pahl et al, 2007, Howard et al, 2008]. A well accepted generic model of design processes exists out of different stages; analysis, generation, evaluation and modification [Tomiyama and Schotborgh 2007]. There is 'sufficient' knowledge about what designers should do in the analysis, evaluation and modification stages. However there is no single theory that explains the generation stage for a variety of design synthesis. Instead there are a variety of theories and models that can explain only a very limited type of design synthesis [Tomiyama and Schotborgh, 2007].
Models are needed to bridge the gap between the worlds of Prescriptive Design Methodology and Reflective Practice, and to look at designing as a process in which the concepts of function, behavior and shape of artifacts play a central role [Vermaas and Dorst, 2007]. Such integrated approach shows high promises to reduce failure costs and improve design quality can eventually lead to integral process, team and method – all the required conditions for design of the end product; the building [Seppänen et.al., 2007]. That is why the building design community is showing a growing interest in models of design as a supportive framework for the building design process.

2. Methodology

This research started by determining the added value of applying a design method in the multi-disciplinary domain of building design. One of the tools within the chosen design method, the morphological chart, was extended into a morphological overview. This approach was tested in workshops being a research setting as close to practice as possible. The structure and content was developed in an iterative way, starting with set up derived from some earlier experiments. During the evaluation of the workshop which was done on basis of questionnaires filled in by the participants there was a need to look more closely into the working of the morphological charts and morphological overview. A theory is needed to focus on the different actions that took place in the knowledge exchange and developing process. C-K theory of [Hatchuel and Weil, 2003] was used to make these steps explicit. In this part of the research the focus was on the application of C-K.

Integral Design method

At the University of Twente in the Netherlands a successful design approach was developed for the mechanical engineering domain by van den Kroonenberg and elaborated theoretically by de Boer [1989] and Blessing [1994]: Methodical Design. When developing his design method van den Kroonenberg took only the most essential elements of the many different design methods that were proposed by the German and the Anglo-American design schools at that time. He focused on the need for a methodical ordering of the design activities in an overall design framework and looked at the difference between research and design in analogy with general system theory [Bertalanffy, 1951, Blanchard and Fabrycky, 2005].

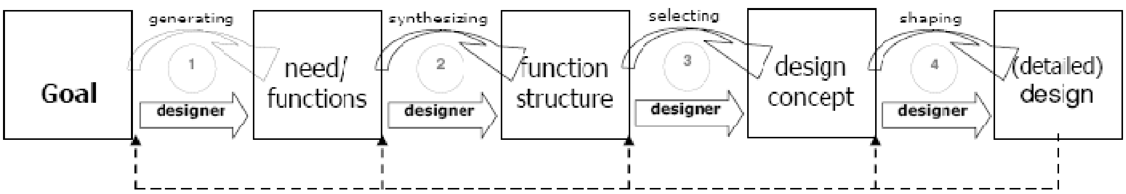

Figure 1. The four-step pattern of Integral Design with possible iteration loops

Using the analogy with general system theory van den Kroonenberg thought of a design process as a chain of activities dived into stages and steps, which starts with the abstract formulation of the design need and results in a specific solution for that need. Stages have been defined as a subdivision of the design process based on the state of the product under development. A step or is a design activity defined as a sub-division of the design process related to the individual problem solving process rather than to the state of the product under development as reflected in the stage division. Compared to stages, activities are specific design steps e.g. generating, synthesizing, selecting and shaping

[Blessing 1994]. The basic three-step cycle of methodical design(generate, synthesize, shape) is extended by us to stress the importance of the decision making in the design process. Thus, a distinctive feature of the integral design model is the four-step pattern of activities (generating, synthesizing, selecting and shaping, see figure 1).

Morphological Overview

A distinguishing feature of Integral Design is the use of morphological charts for synthesis steps within the design process. Morphological charts were first used by Zwicky [Zwicky, 1948]. The morphological chart is formed by decomposing the main goal of the design task into functions and aspects which are listed on the first vertical column of the chart which consist of a column and connecting rows. The functions and aspects are derived from the program of demands which defines the outcome of the design process. Possible solution principles for each function or aspect are then listed on the horizontal rows. The morphological chart gives an overview of aspects/functions and sub-solutions that can be combined together to form overall solutions, see Fig. 2 combinations A, B, C and D.

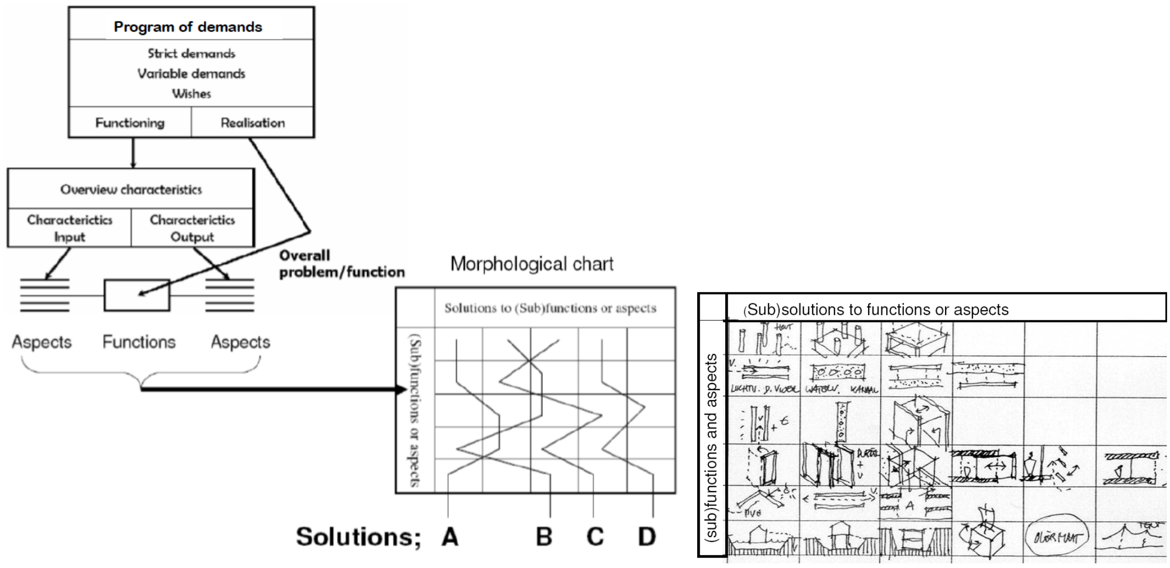

Figure 2. Program of demands as input for the morphological chart

The morphological charts made by each individual designer can be combined into a (team) morphological overview. This leads to an overview of different interpretations of the design brief as a result of the domain specific morphological chart from each design team member. The whole process is done in two steps: first the functions and aspects are selected and put in the first column, and then the possible related solutions are added, see Fig. 3.

The approach was tested in workshops, which will described later in this article, to determine if the application led to positive effect for professionals [Savanovic, 2009]. Although the results were positive we realized that in this approach the focus was on the known (sub) solutions and creation of possible combinations between strategy as part of the prescriptive integral design method.

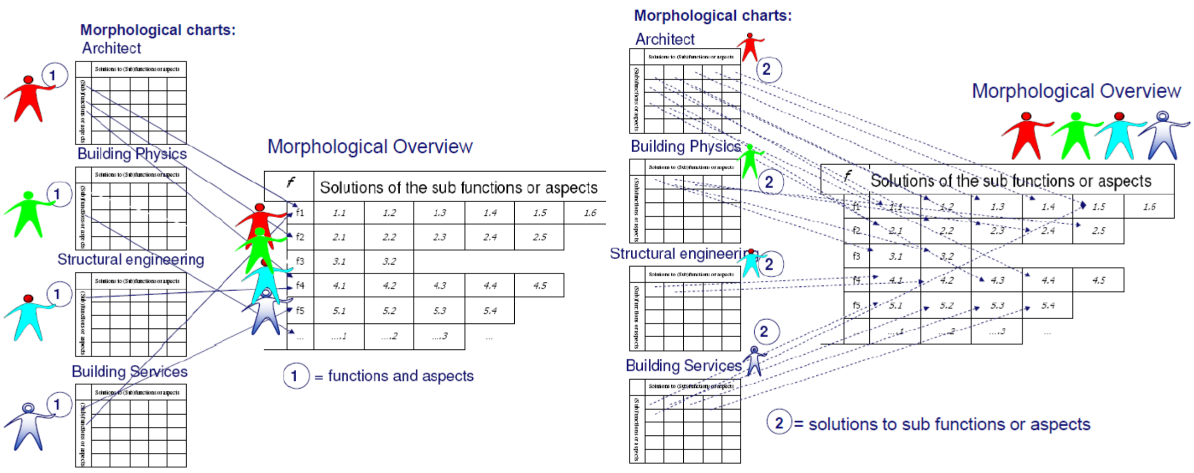

Figure 3. Building the morphological overview; Step 1; The Morphological overviews show the agreed functions and aspects (1) of the different morphological charts. Step 2: The Morphological Overview with the agreed on sub solutions (2) from the separate morphological charts

4. Experiments: Workshops for Professionals (architects and consulting engineers)

An essential element of the workshop, besides some introductory lectures, was the design cases on which the teams of designers had to work and which they had to present at the end of each session to the whole group. These design exercises were derived from real practice projects and as such were as close to professional practice as possible. The participants were members of the professional organizations of archtitects (BNA) and engineers (NLIngenieurs) in the Netherlands and had on average 12 years experience. Different settings were tested and the final setting was repeated. In each workshops up to 7 teams, existing of an architect, structural engineer, building physics engineer and building service engineer, participated [Savanovic, 2009]. All sessions were videotaped and additionally photographs were taken every ten minutes. The end presentations and all used material, sketches etc. were also photographed.

In total 5 series of workshops were organized based on earlier experiments. After each workshop the set-up and the results were evaluated and adjustments made. The experiences of the first three workshops 'learning by doing' series led to a final setup for the workshops series 4 and 5. The 4th workshop was held in May 2007 and the 5th workshop was held in February 2008. Essential element of the workshop were besides some introduction lectures the design cases on which the teams of designers had to work and which they had to present at the end of each session to the whole group. These design exercises were derived from real practice projects and as such as close to professional practice as possible. In the current configuration (see Figure 4) stepwise changes to the traditional building design process type, in which the architect starts the process and the other designers join in later in the process, are introduced in the set up of the design sessions.

The first two design sessions on day 1, provide reference values for the effectiveness of the involved of all designers from different disciplines right from the start. On the 2nd day the morphological overviews introduced. The application of morphological overviews during the set up of the third design session enabled transparent structuring of design functions/aspects and the generated (sub) solution proposals. Additionally, the third setting provided the possibility of one full learning cycle regarding the use of morphological overviews. After the feedback about their use of morphological charts and the morphological overview all teams had the basic knowledge to apply them correctly.

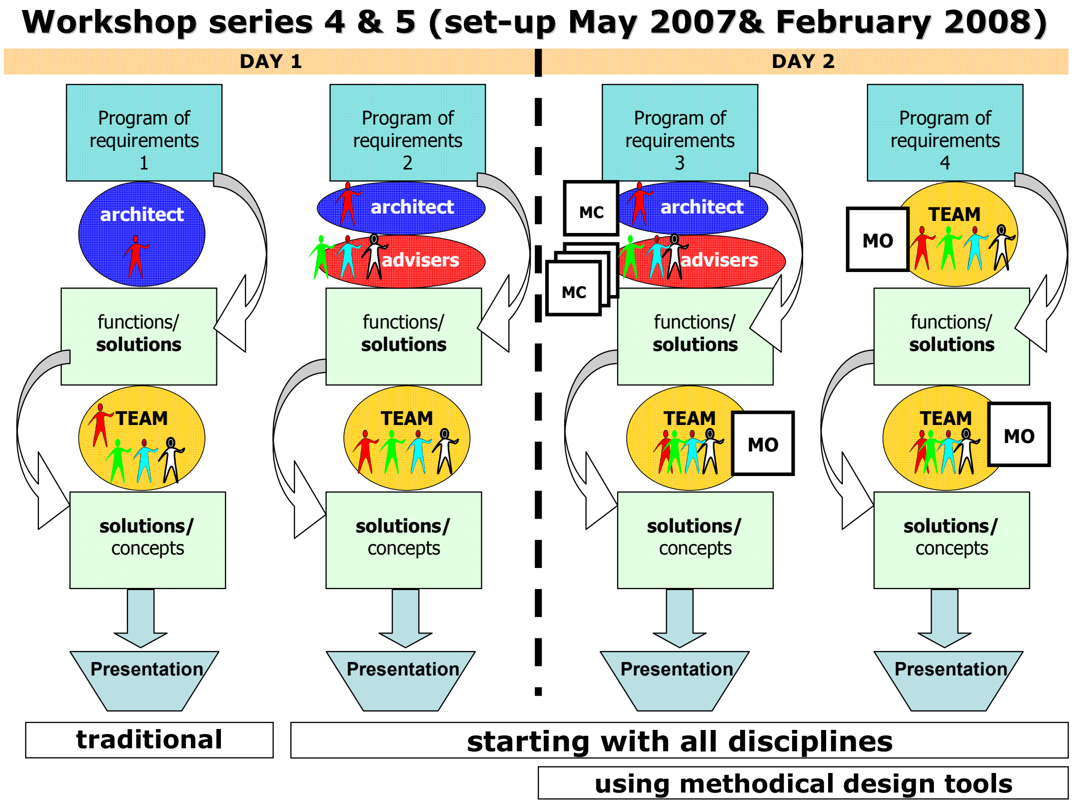

Figure 4. Workshops series 4 & 5, four different design set ups of participants and Morphologic Overviews (MO) during the four design sessions within two days(Savanovic 2009)

5. Results integral design workshops

Here only a brief selection of all the results is given. More results and information is presented by Savanovic [2009]. Over the past four years the above described approach was tested in a series of 5 workshops, these typically include around twenty participants and lasted for two or three days. A total of 108 designers participated in the five workshop series. The average age of the participants, either architect or engineer was 42 and they had on average 12 years of professional experience. Direct at the end of the workshop the participants were asked to fill in a questionnaire in which questions were asked about the importance of the use of morphological overviews within the design process. The participant had to rate between 1 (very poor) to 10 (excellent), the different aspects and their results were then transformed to an average group rating see figure 5.

From the analysis of the results of the workshops it could be concluded that the solution space, resulting from the number of functions and aspects considered, was significantly increased by applying the Morphological Overviews. A good example of this increase can be seen from the results from session 1 (without morphological charts and morphological overview) compared with the results of session 4 (with use of morphological charts and morphological overview). The increase of the number of considered functions and aspects leads to a larger number of partial solutions which implies an increase solution space, see Fig. 6. The comparison of setting 1 and 2 presents the effect of introducing the different designers from the start without using support. This led to a decrease of the number of aspects and (sub)solutions, indicating a less effective design process.

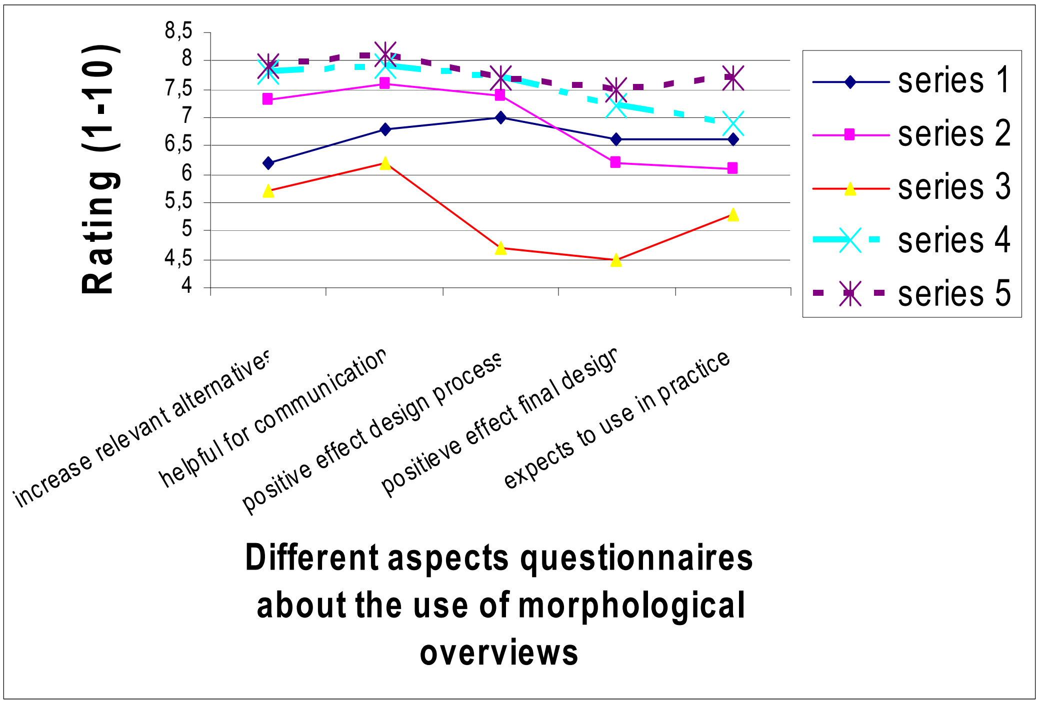

Figure 5. Overview results questionnaires participants workshops series 1 till 5.

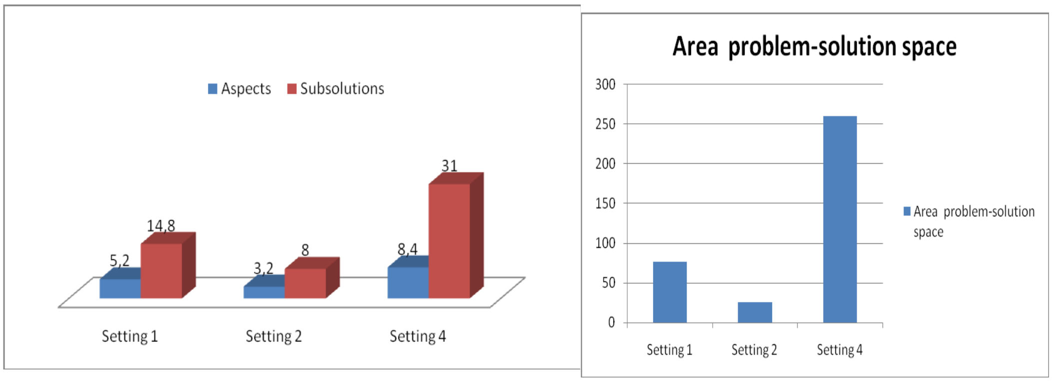

Figure 6. Comparison of the number of aspects/functions and the number of partial solutions being generated by the design teams in designsession 1 (without morphological tools) and design session 4 (with morphological design tools) and as an overall indication the 'problem-sulution'area defined as the number of aspects times the number of solutions

6. The distinction between the known and the conceptual: K and C

Prescriptive methods for structuring design processes based on the existing theories of design still predict designer's actions only on an overly abstract level. Designers specifically know the artificial world, the 'conceptual' world, the human-made world of artifacts. Designers know how to propose additions to and changes to the artificial world. Their thinking, knowledge, skills, and values lie in the techniques of the artificial, the conceptual (Cross 2001). A model to integrate this is the simplified model by de Vries (1994). Consider an individual designer working on a design problem here two worlds can be distinguished connected to the activities taking place. One world consists of the design object, the object description and the design knowledge all part of the real world, the knowledge world K, while there is also a hidden undefined 'artificial', conceptual world C in the mind of the designer. This distinction relates to the core propositions of C-K theory [Hatchuel and Weil 2007].

C-K theory uses four different operators to explain the whole design process, two ‘external’ (from C→K and from K→C) and two ‘internal’ (from C→C and from K→K), resulting in the so called C-K design square [Hatchuel and Weil 2003]. The first two operators cross the Concept-Knowledge domain boundary, and are significant in the sense that they reflect a change the logical status of the propositions under consideration by the designer (from no logical status to true or false, and vice versa). Proposed as a unified design theory, C-K theory focuses on innovative design [Hatchuel & Weil 2003]. However, the majority of cases in design do indeed concern mere computation, optimization and/or combinatory, which we would also like to capture as the possible outcomes of design meetings. Therefore, we propose the distinction between ‘integral design concepts’ (ID) and ‘redesigns’ (RE) [Savanović 2009]. Individual designers explicate their object design knowledge (iODK) by generating object-design representations, shown as small circles in Fig. 7. From here, two types of synthesis are possible: either the representations are combined into ‘redesigns’ (RE) or transformed into ‘integral design concepts’ (ID).

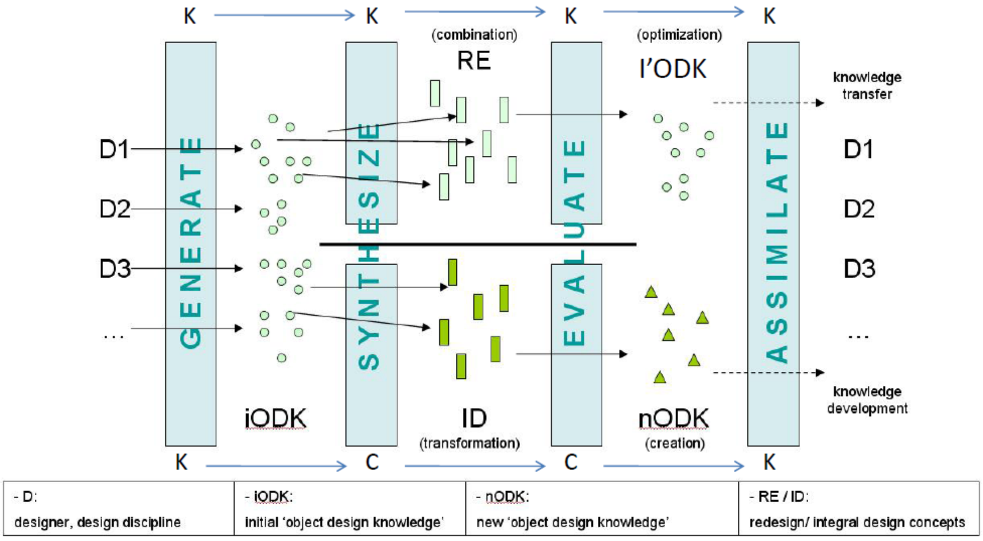

Figure 7. A model of knowledge transfer and knowledge development within the C-K design square

The upper part of Fig. 7 represents creation of redesign (RE), K-K transformation, while the lower part of Fig. 7 represents creation of integral design (ID), C-K transformation. Of course, there is always the possibility to discard the presented knowledge as not relevant. Evaluation of ‘redesigns’ (RE) results in the optimized initial object design knowledge (i’ODK), K-K transformation, while from ‘integral design concepts’ (ID) completely new object design knowledge (nODK), C-K transformation, can be created. The difference between the two design processes visualized in Figure 1 is that the first one results in knowledge transfer between the designers/participants involved, while the second one allows the possibility of knowledge development. One could argue that for the creation of ‘redesigns’ (RE) only design skill as a general human ability [Cross 2006] is required, while the creation of ‘integral design concepts’ (ID) involves design thinking and creativity.

7. C-K theory applied to Integral design’s morphological overview

Within this research, a multidisciplinary building design team, the available knowledge within this team represents space K. The overview of this knowledge is captured using morphological charts. Within the integral design method, the individual charts are combined into one morphological overview containing all selected sub solutions by the individual team members. The next step can take two forms, see Fig. 8 :

I. design team combining sub solutions into RE-designs
II. design team transforming object-design-knowledge into ID-concepts

The working design two-step model distinguishes between redesign (K-K) and concept generation (K-C). The elements IDx6, IDy1 and IDy2 represent conceptual sub solutions as a result of the concept generation K-C, see Fig. 8. This distinction is crucial since, we firmly believe, that the development of new concepts is essential if we would like to generate creative solutions to the highly complex contemporary design problems that our societies face.

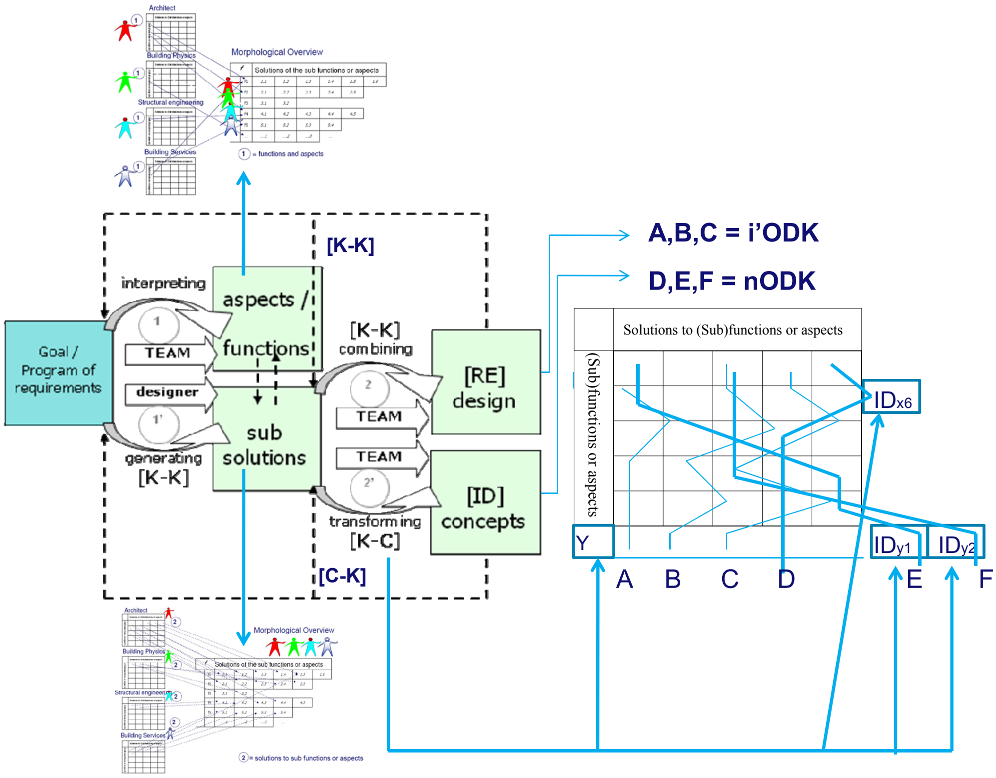

Figure 8. Working Design model C-K theory illustrated by morphological charts and morphological overview

8. Discussion

The research was performed on the boundaries between design and scholarly research but in the end the focus was on design itself and that meant that the results were not validated against some criteria but by criteria of the workshops participants themselves. Did the approach have some added value for them? The results of the questionnaires indicate that this was the case on most aspects, though not on all. This is also an important aspect for further analysis of the workshops.

Although morphological chart can be used effectively without any theoretical back-drop, the use of the C-K theory and its application of the four operators (K-C, C-K, C-C and K-K) enabled us to focus on the transformation that take place in the design team between the individual designers.

What was quite remarkable from the analyses of the in total 11 design teams of workshops series 4 and 5 was that there were no new solutions based on elements of new concepts: all solutions resulted from known partial solutions. The extension of the morphological overview with new aspects/ functions or (sub)solutions did not occur after the merger of the morphological charts. There was no nODK only i'ODK, see Fig. 7. The professionals stuck to the known solutions and variations made from them.

9. Conclusions and further research

The use integral design with its morphological charts and morphological overview made it possible to apply a new tool to better organize the design knowledge within a design team. This approach clearly led to an increased problem-solution space. This is a good indication of a more effective design process.

Analyzing the result of the workshops series 4 and 5 we found that the designers did not use concepts to come to their solutions. Thus there was no integral design where concepts were used to generate new knowledge and resulting solutions. Using the C-K theory and the morphological overview to make the transformation process of knowledge to solutions more transparent and will enable to focus on specific transformations within the building design process and to look for more supportive tools for design mechanism to stimulate the K-C, C-C and C-K transformation which are involved in concept creation. One such example are the so called C-constructs used by Hatchuel and Weil in their KCP (Knowledge-Concepts-Proposition) workshops [Hatchuel et al 2009] to stimulate the forcing of concepts. The KCP workshops were held in different companies in France and more recently in Volvo in Sweden [Elmquist en Segrestin 2009]. The use of C-constructs could lead to increased effectivness of the Integral design workshop, especially to an increase of the solution space by stimulation the transformations of K-C, C-C and C-K.
Another aspect for further research is the argumentation to come to the aspects/functions from the individual morphological charts to the list used in the morphological overview. This K-K transformation will be studied by analyzing the argumentation which leads to the team decisions on these aspects.

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