INTEGRAL DESIGN AND C-K THEORY FOR CONCEPT GENERATION IN THE BUILDING INDUSTRY

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Innovation in the Building Industry is necessary. This research set out to develop a method that would create the opportunity to introduce a greater variety and amount of design knowledge from the outset of the conceptual design phase and use it for concept creation by applying Concept-Knowledge theory. C-K theory defines design as the interplay between two interdependent spaces, knowledge space K and concept space C, which allows us to conceive of the possibility to transform the building design team's knowledge into new concepts. The Integral Design method developed here, may in time lead to the generation of innovative building concepts that will allow us the opportunity to move beyond redesign and optimization.

Keywords: Integral design, C-K theory, morphological overview, building design.

1. INTRODUCTION

Building and thus building design processes are as old as civilization itself. Ever since Vitruvius' first treatise on architecture, de Architectura of around 25 BC, resulting in the three main principles venustas, firmitas and utilitas, we accepted that an architect must know a little bit about everything because design work requires varied knowledge and an outstanding capability for mental integration and synthesis [1]. Building design often starts with rough initial ideas about the situation in which the building has to be placed and rough initial ideas about the function that the building should have [2]. As the design proceeds, more information and detail are developed leading to problems in relation to specific conflicting functionalities required from different disciplines. These problems cannot be solved by any one design discipline alone and require multiple disciplines with a shared theoretical understanding and an agreed interpretation of knowledge [3]. This knowledge is the starting point of creative collaborations that cross disciplinary boundries and is essential to innovation. This can lead to the occurance of boundary spanning, where ideas from one domain, discipline or functional area are important into another [4], in a way that solves new problems or presents new solutions [5, 6]. However, just putting people with diverse perspectives and from different disciplines in the same room is no guarantee that effective boundary-spanning collaboration will occur [4]. The size and specialization of modern professionals makes finding the right conceptual bridge between domains difficult for an individual designer to solve the complexcity on it his own. Therefore collaboration is required for innovation [4]. Through this collaboration experts recognize the analogous qualities of ideas from distant conceptual realms, identify ways they can be usefully connected and work to realize them [5].

The goal of this paper is to look for posible ways to support the collaboration between designers in the conceptual building design phase. To do this we started to look at design methods and design theory. Especially our focuss was on operationalisation of the Concept-Knowledge theory by Hatchuel and Weil [7, 8]. The clear distingtion between existing knowledge within the design team and possible concepts is helpfull for the focus on creating new solutions.

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2. METHODOLOGY: C-K AS DESIGN THEORETICAL CONCEPT

2.1. Starting from knowledge

The origins of design methods in the 1960s were based on the application of 'scientific' methods derived from operational research methods and management decision-making techniques in the 1950s [9]. In the 1980s engineering design methodology of the systematic variety developed strongly and it was a period of substantial revival and consolidation of design research. Since then there was a period of expansion through the 1990s right up to day: design as a coherent discipline of study was definitely established in its own right [9]. Still there is no clear picture [10, 11] and many models of designing exist [12–15]. Therefore we started to analyze the existing conceptual building design process.

Generally speaking, building design is a creative process based around the transformation of knowledge and information about the actual spatial needs of a principal into a solution to fulfill those needs; a building. The knowledge and information has to be transformed into new unknown concepts if solutions based on existing knowledge are not adequate.

In the traditional building design process the architect starts alone and immediately starts thinking of a solution to the needs of the client although the design brief is not clear enough. From that moment on he mainly can make combinations and variations around that first idea and as a result of this mental blockade his possible solution space is restricted, see Figure 1.1 [16].

We looked at how the building design changes when the other building designers such as building services engineers, structural engineers and building physics engineers join the architect in the conceptual design phase, see Figure 1.2. Through the creation of knowledge based on diverse skills, experience and information exchange, the quality of design process and the creative performance of design teams improve [17]. Due to the cognitive diversity among team members in terms of knowledge and skills there is a broader access to information and knowledge, creating more and different insights in to the current design task and its problem field [17–19].

In our approach to analyse the building design process we made the distinction between the solution space of the known (K) and the possible solutions in in unknown, concepts (C) which have an undetermined status (either true or not), in analogy with the C-K theory of Hatchuel and Weil [8]. This dictinction between concepts and knowledge by Hatchuel and Weil [20, 21] is simular to the model for conceptual design by Jansson [22], were the conceptual design process is described as movement between two spaces: configurations space and concept space. Hereby differs the concept space from the configuration space in that the elements its contains are ideas, relationships, or other abstractions, which may later become the basis for elements in configuration space.

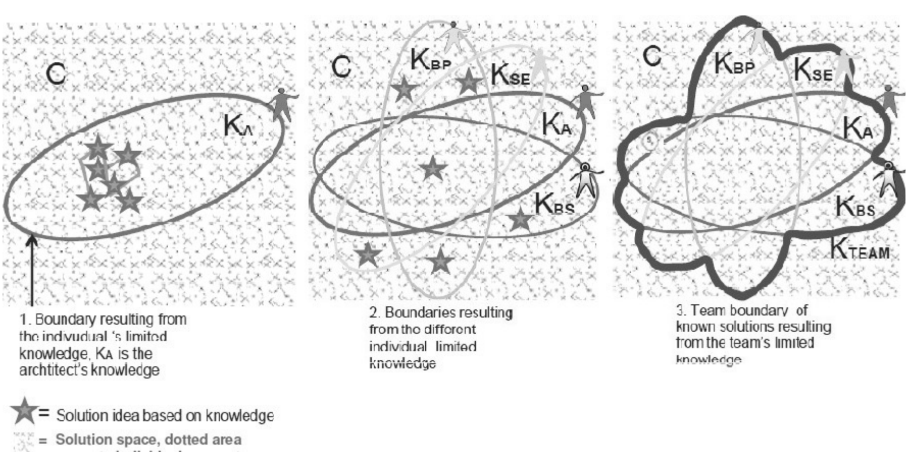

Figure 1. The individual solution space of the architect (1) versus the individual design team member's solution space (2) and the resulting maximum team's solution space (3).

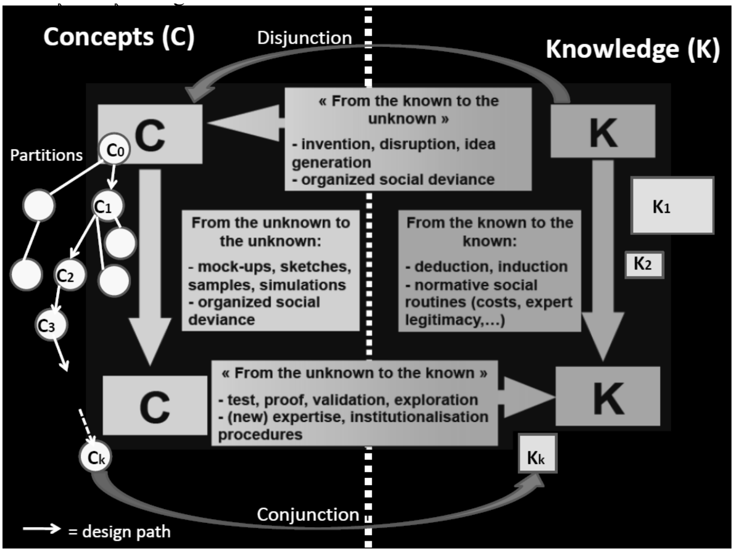

Figure 2. The C-K design square [25].

C-K theory defines design as the interplay between two interdependent spaces having different structures and logics. This process generates the co-expansion of two spaces, space of concepts C and space of knowledge K. Since C-K theory defines a piece of knowledge as a "*proposition with a logical status for the designer or the person receiving the design*" [7].

First, we start with the knowledge related solution space of the architect, K_A (Figure 1.1) then the other design team members join in; Structural Engineer K_{SE}, Building Physics consultant K_{BP} and Building Services consultant K_{BS} (Figure 1.2). Instead of focusing around one solution, different options from different disciplines are proposed (Figure 1.2), which leads to new interactions and new possible solutions. The resulting solution space of the design team is in principle clearly bigger than that of the architect alone (Figure 1.3).

2.2. From knowledge to concepts

From the perspective of C-K theory, the initial object-design-knowledge that participants bring into design team defines space K. From here, two types of synthesis are possible: either the representations are combined, using the K•K operator, or are transformed, using the K•C operator. A space of concepts is necessarily tree structured as the only operations allowed are partitions and inclusions and the tree has an initial set of disjunctions [23]. A design solution is given by the first concept C_k to become a true proposition in K (see Figure 2). The other branches of C are concept expansions which do not reach a proposition that belongs to K [24]. If we add new properties (K•C) to a concept, we partition the set into subsets, see par example C_1 in Figure 2; if we subtract properties, we include the set in a set that contains it. No other operation is permitted. After partitioning or inclusion, concepts may

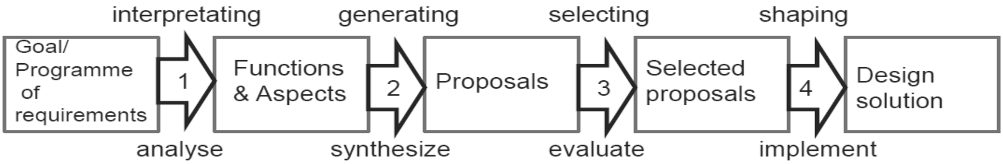

Figure 3. Four-step pattern of Integral Design.

still remain concepts (C•C), or can lead to creation of new propositions in K (C•K), see C_k to K_k in Figure 2.

2.3. From design theory to design method: Integral design as systematic intervention

We choose Methodical Design as developed by van den Kroonenberg as a starting point, as it is based Systems theory and on a synthesis of the German and Anglo-American design models of the mid seventies [26] and as such has exceptional characteristics [27]. Methodical Design distinguishes three main phases or stages (the problem definition, the working principle determination and the detailed design), and four specific design steps (generating, synthesizing, selecting and shaping). Dividing a design process into stages and steps is important to decompose and structure the process around more manageable tasks. The transition between steps provides decision points, forcing review and evaluation of the results generated so far. Starting from the prescriptive model of Methodical design a method, Integral Design, was developed to articulate the relationship between the role of a designer as descriptor or observer within the design team and to reflect on the process [28]. The Integral design method, though based on methodical design, is an extended design method; the cycle (define/analyze, generate/synthesize, evaluate/select, implement/shape) forms an integral part in the sequence of design activities that take place, see Figure 4.

2.3.1. Morphological overview

A distinguishing feature of Integral Design is the intensive use of morphological charts to support design activities in the design process. 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, with related subsolutions listed on corresponding rows. The functions and aspects are derived from the program of demands. Possible solution principles for each function or aspect are then listed on the horizontal rows. Different overall solutions are created by combining various solution principles to form a complete system combination [29]. The main aim of using morphological charts is to widen the search area for possible new solutions [30].

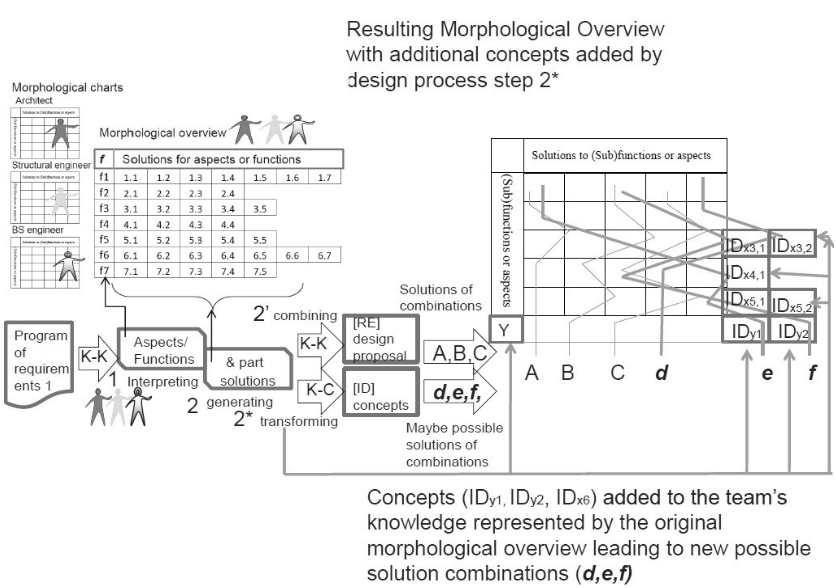

Figure 4. The ID-method steps according to the C-K theory operators.

The morphological charts made by each individual designer, representing his knowledge related to the design task, can be combined into a (team) morphological overview after discussion on and the selection of functions and aspects considered important for the specific design. This combines knowledge from one discipline which could be concepts for other disciplines. As such this intervention in the design process is a mechanism of organized social deviance which triggers the generation of concepts.

The advantage of this approach is that the discussion begins after the preparation of the individual morphological charts. This allows each designer to develop his own interpretation and representation, in relation with his specific discipline based knowledge and experience. This interpretation than can be combined with the interpretations by the other designers into a morphological overview. The different interpretations of the design brief result in a team specific morphological overview based on the morphological charts chart from each design team member. Importantly, this encourages and allows engineering based disciplines to think and act more freely than is common in the traditional design approach. In sum, this approach allows a greater freedom of mind of the individual designers and results in more creativity in interpretation of the design problem and generation of sub solutions from the different disciplines.

2.4. Integral design and C-K theory

Morphological charts and overviews can be used to generate, define and record design aspects/functions and sub solutions. Within the Integral Design approach, after the first step of generating discipline specific morphological charts and discussing the results as a team, the individual charts are combined into one morphological overview containing all of the useful sub solutions from the individual team members. The next step is for the team to take the knowledge and ideas from the overview and translate them into a proposed design solution, see Figure 4.

This step can take two forms: either the design team combining sub solutions into RE-designs or the design team transforming object-design-knowledge into ID-concepts. The Integral Design model combined with the C-K theory forces the focus on the distinction between redesign (K-K transformation leading to RE) and integral design concept generation (K-C transformations leading to ID-concepts). The elements ID $\times$ 6, IDy1 and IDy2 represent conceptual sub solutions as a result of the concept generation K-C, see Figure 4. This distinction is crucial to stimulate the development of new concepts to generate creative solutions. When applying the transformation of the morphological chart into the morphological overview in the C-K square we could consider the individual morphological chart from one disciplines as a concept for the other disciplines as it contains unknown solution for them. Also the solutions from one discipline might to be a possible solution in combination with the interpretation and solutions from the other disciplines. So in the first step all the elements from the morphological chart become concepts for the design team (K-C transformation). Only after discussing and putting elements from the morphological charts in the conceptual morphological chart (C-C transformation) it becomes clear to the team which from the unknown combinations are suitable solutions in relation to the specific design brief (C-K transformation), see Figure 5. Those elements of the individual morphological chart that are known by all design team members can be put directly into the morphological overview (K-K transformation).

3. EXPERIMENTS

The next step was to test our approach of Integral Design with its use of the morphological overviews and C-K theory. Therefore, we arranged workshops as part of a training program for professional architects and consulting engineers [structural engineers, building services engineers and building physics engineers]. The goal of the training was to teach the participants the principles behind the integral design method and to train them in the use of morphological charts and morphological overviews as the design tools. We did not want to stress the scientific approach behind the set up and the goal of the workshops as the practitioners are more interested in methods and tools than in scientific theories. Therefore there was no mentioning about the underlying C-K theory or of the experiment

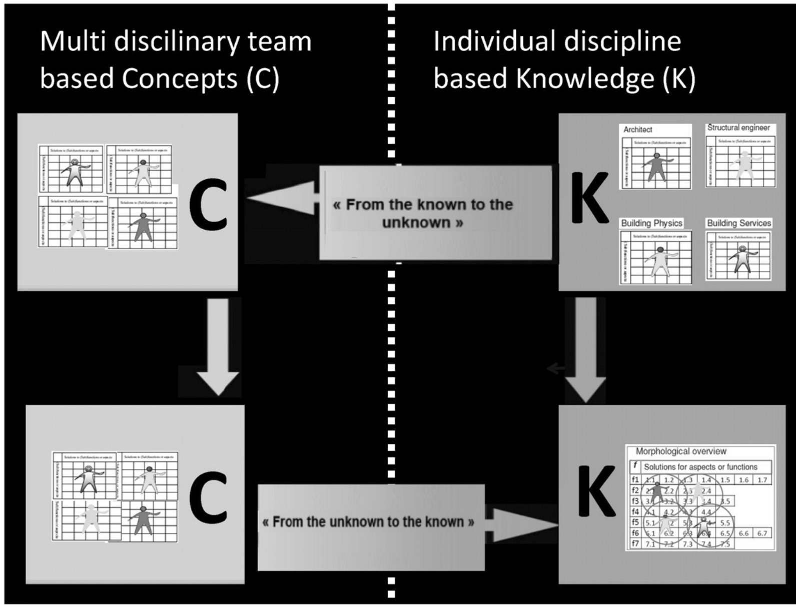

Figure 5. The ID-method steps with morphological charts and morphological overview according to the C-K theory transformations: K-C, C-C, C-K and K-K).

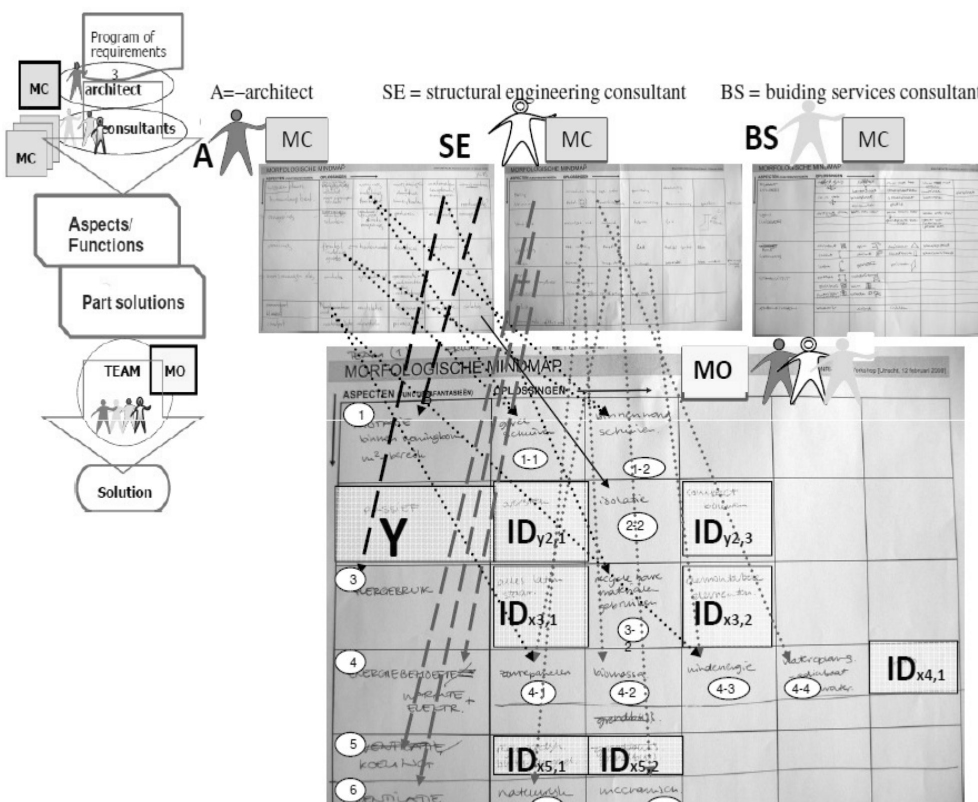

Figure 6. The workshop set-up and a design team's morphological overview.

we were doing. So for them it was a workshop on Integral Design in learning by doing approach. On average these participants had 12 years of professional experience. An essential element of the workshop, besides some introductory lectures, was the design cases, on the basis of which the design teams worked and presented their ideas/design at the end of each session to the whole group [28]. These design exercises were derived from real practice projects and as such were as close to professional practice as possible. As an example the morphologic charts and the resulting morphological overview of a design team in a workshop session is displayed in Figure 6. The new function is coded Y and the new concepts are marked by the squares in the morphological overview and coded according their belonging to an existing function X, IDx, or the new function Y, IDy.

4. DISCUSSION AND FURTHER RESEARCH

In the built environment there is a pressing need for new solutions. Therefore the focus in building design should be on the stimulation of new concepts. In this research the main area of interest lies in the conceptual phase of the design process.

The use of morphological charts and morphological overviews makes it possible to analyze the team process and focus on the concept generation. Integral design with its use of morphological overviews in combination with the C-K theoretical framework on concept generation is an important step to reach for innovations in sustainable building design. The Integral Design approach generates concepts using the morphological overview to make the knowledge domain related to the design task in relation with the C-projectors. This paper shows that morphological charts and morphological overviews can be used retrospectively in combination with C-K theory. However the morphological overview can be used to further stimulate connections between space C and space K, with the introduction of additional tools to stimulate the transformations from K to C. From these new K-C connections from out the morphological overview, it may be possible to derive new concepts. These C-constructs are domain strange concepts, which are used as a source of inspiration for further research to make a connection between the existing domain knowledge in space K, and so determine the possibility of concepts resulting from these new connections. After this evaluation these concepts become part of K, allowing the C-K transformation to take place. In a way the individual discipline specific morphological charts could at least partly be seen as C-consruct by the other disciplines. In this perspective the funtions/aspects interpretation of the design brief, resulting in the individual morpholocal charts, act as a kind of identified operators.

In this paper we looked into some of the factors influencing design team's creativity (method and tool) in relation with the C-K theory to focus on different steps in the design process to stimulate concept generation. In our future research we want to develop tools and procedures to stimulate the generation of concepts from out the knowledge represented in a transparent way in the morphological overview of a design team.

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