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MORPHOLOGY TO ILLUSTRATE THE MENTAL MODEL OF A DESIGN TEAM'S PROCESS

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ABSTRACT
The need for nearly zero energy and environmentally sustainable buildings introduced further complexity in the design process of buildings. This calls for a holistic integral design approach with the involvement of besides architects various design experts from different domains to form multidisciplinary design teams right from the conceptual design phase. Mental models can be used to explain the way members organize and present knowledge about the design task that enable design teams to perform its work. To support this process a design method based on the use of morphological charts and a morphological overview was developed in cooperation with the Dutch professional organizations of architects and consulting engineers. This method was implemented in the master education of the Faculty of the Built Environment of the TU Eindhoven. The morphological approach is discussed in relation the theoretical design construct of mental models of the conceptual design process. In this paper, in addition to a detailed discussion on the mental model of a design team, shows the use of the morphological approach and mental model to illustrate the design process of a group of professional designers in a real project setting.

Keywords: Mental model, Morphological Chart, Morphological Overview, Integral Design.

1 INTRODUCTION

The conceptual building design phase is crucial in the overall design process as it determines the life-cycle quality and owner value of the building. The increased complexity of sustainable building design inevitably calls for more design collaboration [Lee and Jeong 2012] and a holistic design approach. In building design recently an 'integrated project delivery' model is followed which 'brings the full building team to the table at a project's inception, where common goals are accepted and each professional's expertise is utilized to improve efficiencies and constructability' [Horwitz-Bennett 2011, Kasali and Nersessian 2015]. The benefit of this type of integrated project delivery is to accommodate simultaneous and continuous input from all disciplines involved, from the first envisioning to the final construction phases. However, such delivery models add more complexities to the routine of building design for the building design team involved [Kasali and Nersessian 2015]. There is therefore the need for design support to facilitate interaction and information exchange between the various design team members.

2 MENTAL MODELS IN DESIGN TEAMS

Researchers in several disciplines have applied the construct of mental models to understand how designers perform tasks based on their knowledge, experience and expectation [Badke-Schaub et al 2007]. Mental models are often seen as critical indicators of team success [Kennedy and McComb 2010]. The concept of mental models was first proposed by Craick [1943] in order to explain human coping behaviour within a complex world [Casakin and Badke-Schaub 2013c]. Mental models are hypothetical constructs that cannot be ideally directly measured [Neuman et al 2006]. Starting from the four models that are commonly used by Cannon-Bowers (the task model, the equipment model, the team model and the team interaction model) Badke-Schaub proposed a modified framework for design activities [Neuman et al 2006, Badke-Schaub et al 2007] (see Fig. 1). Team Mental Models are not meant to only refer to multiple levels or sets of shared knowledge. It also refers to a synergetic functional aggregation of the team's mental functions representing similarity, overlap and complementarity [Langan-Fox et al 2004]. Design typically takes part in an organizational context, with relations to clients and users and specific market situation. The way team members perceive and understand reality can vary according to their background knowledge, expertise etc., which have an effect on their mental models [Casakin and Badke-Schaub 2014]. However, through exchanging views with each other, they develop gradually their own team's representations and adapt them to build models shared by the team [Casakin and Badke-Schaub 2013a].

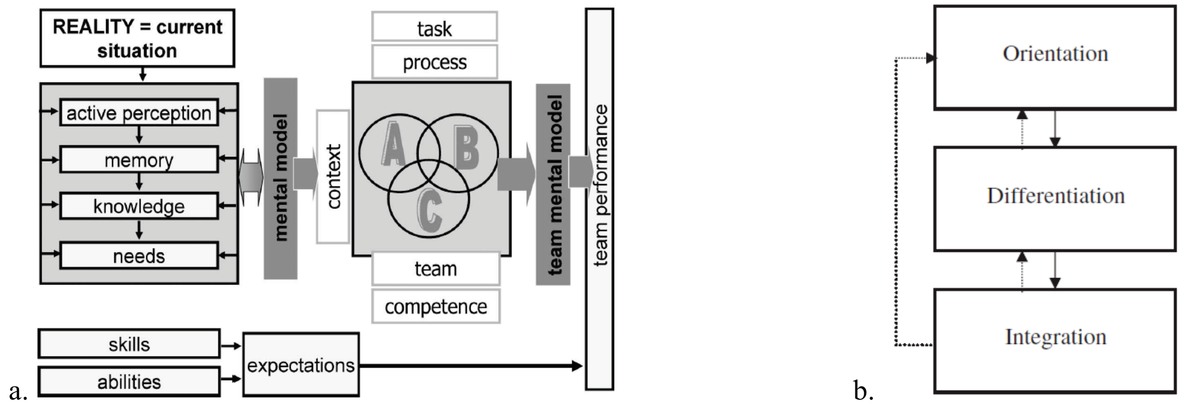

Figure 1. (a) Mental models [Badke-Schaub et al 2007] and (b) McComb [2007]

When team members interact with each other, they evolve and adapt their own mental models and construct a mental model shared by the team [Casakin and Badke-Schaub 2013c]. Figure 1 depicts McComb's [2007] three-phase convergence process framework indicating a directional mental model convergence process with feedback loops [Kennedy & McComb 2010]. First, the team members orient themselves by capturing information pertinent to the task. Second, the team members differentiate among the information gathered to discover similarities, differences or irrationalities in their individual approaches. Third, the information becomes integrated into the team members' views: the individuals' internal representations of the design task from an individual perspective changes into a team perspective [Kennedy & McComb 2010]. Each team member can only be analysed from the exchange of communication acts [Casakin and Badke-Schaub 2013b]. As we wanted to analyse the process within the design team, we looked for ways to make the communication explicit so that it would be possible to analyse the process. Therefore we looked at a way to add an intervention to the process to make this possible.

3 TOOL TO SUPPORT AND ANALYSE THE DESIGN TEAM'S PROCESS

At the University of Technology Eindhoven in cooperation with the professional societies of Architects (BNA) and consulting Engineers (NLIngenieurs) an integral design method was developed for conceptual building design support [Savanovic 2009] and implemented in the master program of the faculty of the Built Environment of TU Eindhoven since 2007 [Zeiler 2013, 2016]. The design method intensively uses morphological charts developed by Zwicky [Zwicky & Wilson 1967]. In the first step 1_i of the integral design method (see Fig. 2), the individual designer has to make a list of the most important functions and aspects that has to be met according the design brief and derived from their own specialist perspective. This is then put into the first column of the morphological chart. In the second step 2_i of the process (see Fig. 2), the designers add the possible part solutions to the related rows of the functions/aspects of the first column. The morphological charts represent the individual interpretation of reality, leading to active perception, stimulation of memory, activation of knowledge and definition of needs. These individual morphological charts are combined by the design team into one morphological overview. First, functions and aspects of each morphological chart are discussed and then the team decides which functions and aspects will be placed in the first column of the morphological overview (see step 1_T in Fig. 2). Second, all participants of the design team can contribute their solutions for these functions and aspects of their own morphological charts or new ideas (see step 2_T in Fig. 2). The morphological charts enables 'the individual perspectives from each discipline to be put on the table', which in turn highlights the implications of design choices for each discipline and stimulates new ideas. Through visualizing the individual contributions within a design team, morphological overviews based on the individual morphological charts stimulate the understanding of different perspectives within design teams. With regard to the problem-solution coevolution approach this is the first phase in the design process where problem and solution co-evolve [Dorst & Cross 2001] along the process as result of the exchange of the different interpretations of the individual designers as represented in their morphological charts and the transformation towards the morphological overview. The design task and potential solutions ‘co-evolve’ in the process where the first column of the morphological overview can be seen as the ‘problem space’ as it has to contain all the important functions and aspects to be fulfilled. The row with sub-solutions of the morphological overview can be seen as the ‘solution space’ [Wiltschnig & Christensen 2013].

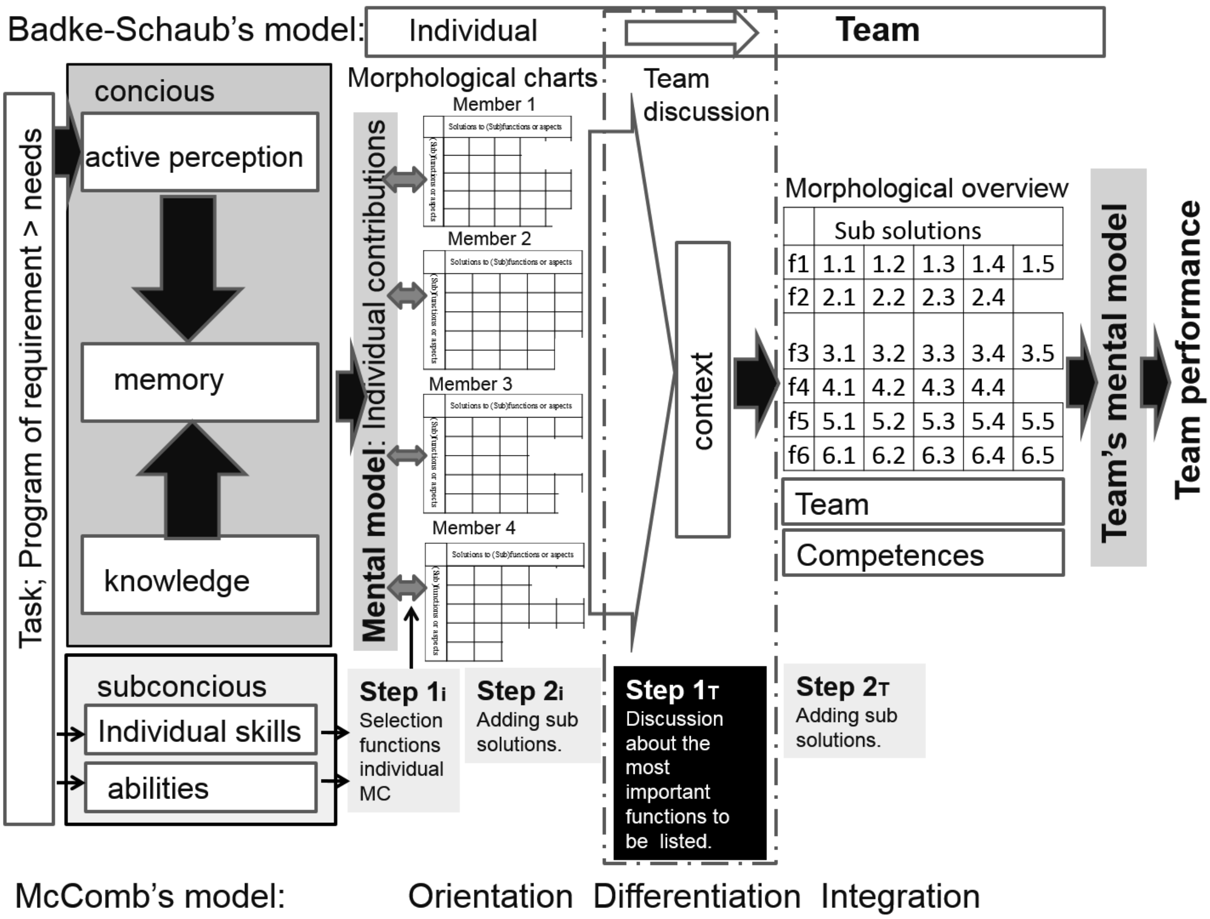

Figure 2. Design Team mental model Morphological Overview in analogy with the model by Badke-Schaub and McComb, in this case with 4 design team members

By applying the integral design method it becomes possible to describe the design process in such a way that it could be used to illustrate the design team mental models of Badke-Schaub [2007] and McComb [2007] and to visualize its development. The morphological charts and morphological overview of the Integral Design method can make the Team’s Mental Model transparent and illustrate the team’s design process. As our research, to find a suitable design tool to support the design education at our faculty, started in industry [Savanovic 2009] and was further developed at university [Zeiler 2016], we now wanted to test our approach in industry again. This to see its effects as well as to demonstrate the added value of mental models to illustrate the team’s conceptual design process.

4 EXPERIMENT: DESIGN WORKSHOP

The goal of this workshop was a kick-off boost for a real project: A new nearly Zero Energy Building to be realized in Netherlands. The workshops existed of an introduction lecture about nearly Zero Energy Building and Design methodology followed by a first training exercise and then the real project assignment session. The design program of the training session comprised a new sustainable and energy neutral office building, where solar-energy can be promoted. Two groups were formed during the start of this first session, they were not influenced by each other since they were placed in two rooms. The groups consisted of: Initiators/Clients, Architect, Building Physics & Services consultants, Contractor and Project manager. After the completion of the individual charts (about 20 minutes) a discussion started about placing the individual functions and subsolutions into the morphological overview (about 40 minutes). No discussion was allowed when completing the individual charts. After completing the first practical session and some feedback the two teams were rearranged and had to follow the same procedure as in the first session; 20 minutes making the individual morphological chart and then 40 minutes to discuss and form the morphological overview as a design team. Fig. 3 shows an example of the transformation from individual morphological charts towards the team's morphological overview. The original charts were translated into English.

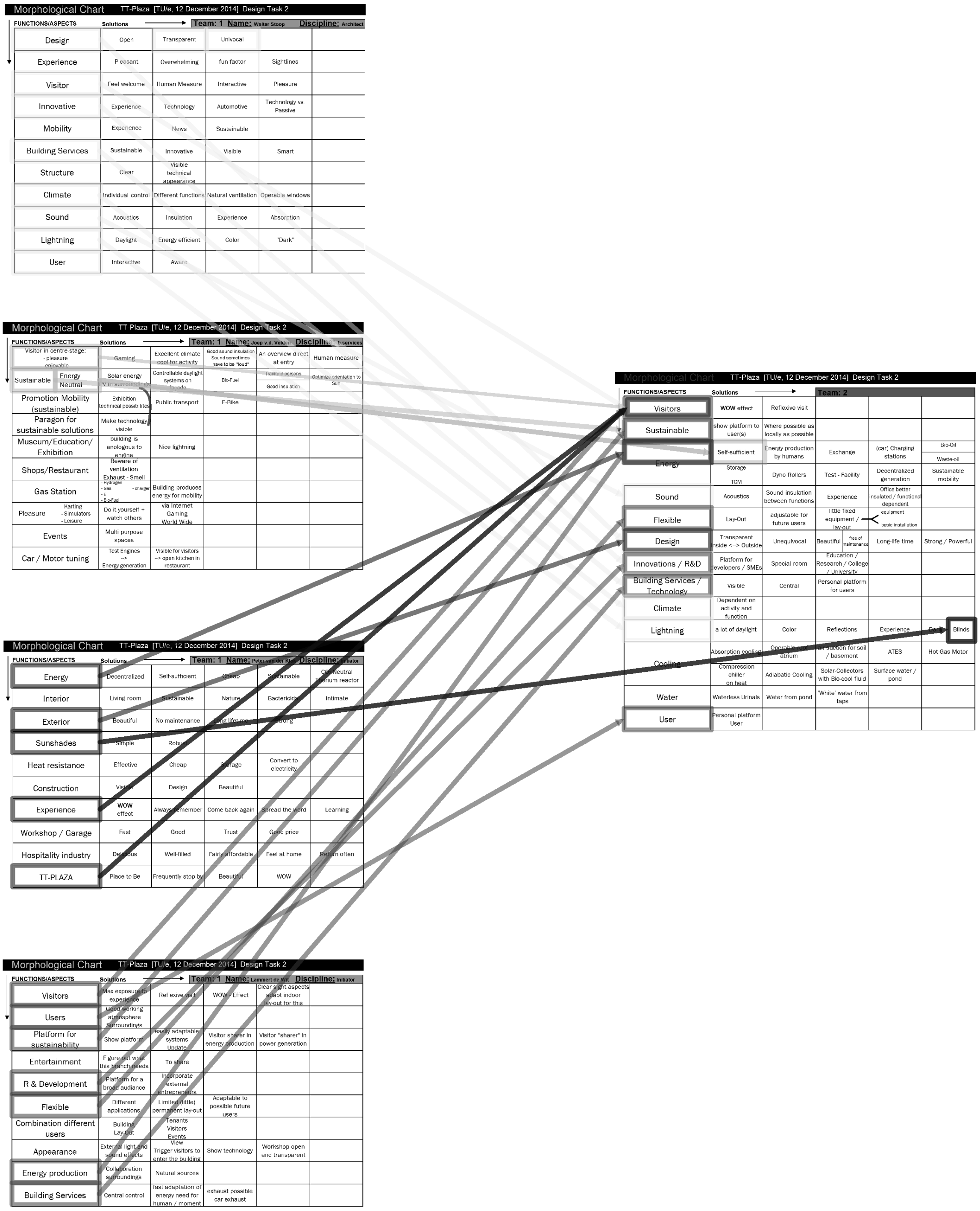

Figure 3. Example transformation morphological charts to morphological overview session 2, team 1

In Fig. 4 of all teams and sessions the transformations from the individual morphological charts towards the team's morphological overview are shown as well as the number of functions/aspects and sub solutions mentioned by each individual and the teams. Counting the numbers of functions/aspects and sub solutions mentioned in the morphological charts and morphological overviews enables to quantify specific effects. For example the effectiveness of the different team members. Based on these numbers the effectiveness of the members are defined in a percentage based on the number of functions mentioned by the specific member in their morphological chart divided by the total number of functions mentioned in the team's morphological overview.

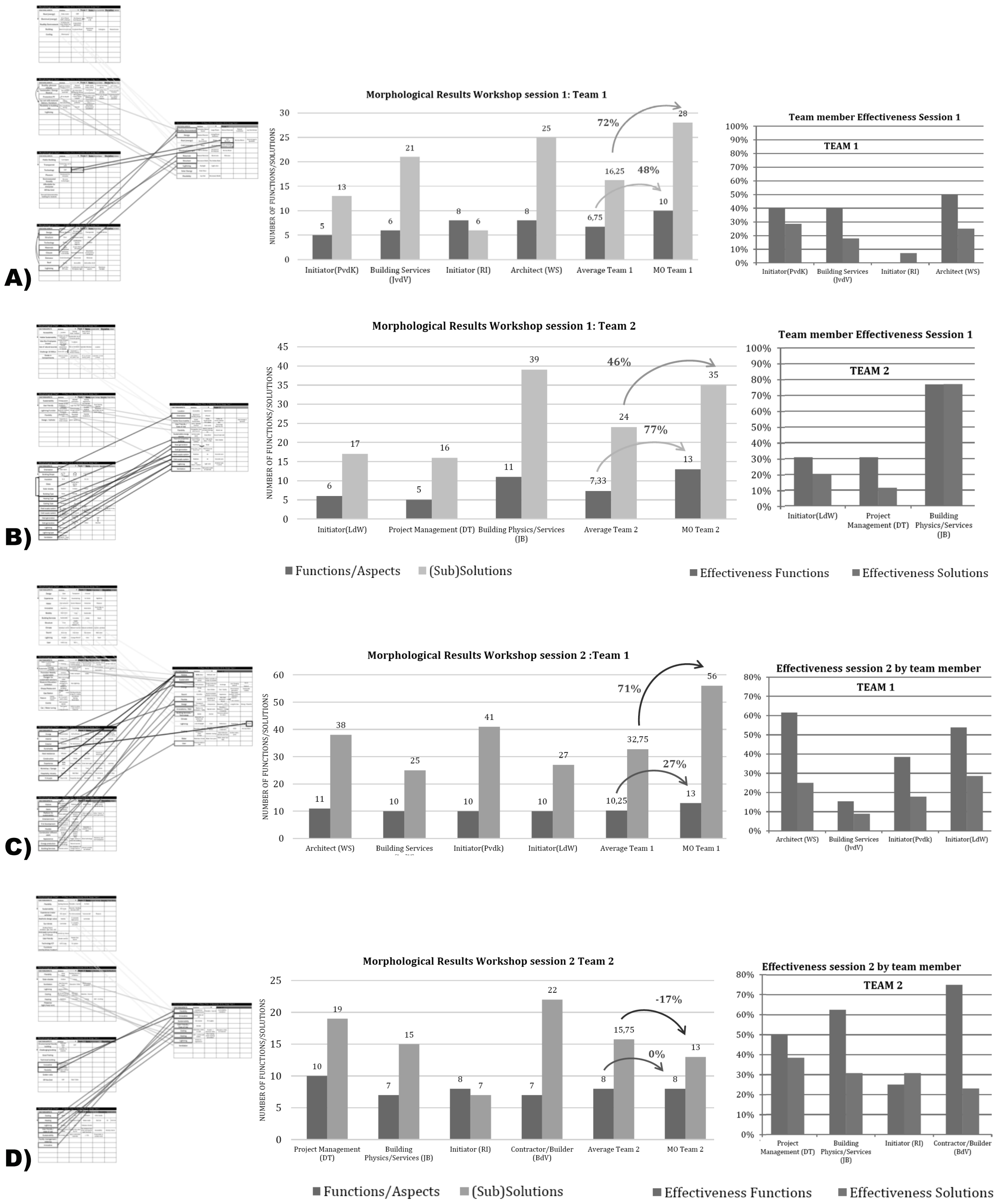

Figure 4. Results of the different workshop sessions 1 & 2, teams 1 & 2

5 DISCUSSION AND CONCLUSIONS

Sustainable building design needs a multi-disciplinary design team already in the conceptual design phase. How knowledge can be better coordinated, communicated and shared in teams that in many cases are heterogeneous and multi-disciplinary is a critical aspect that has not yet received enough attention [Casakin and Badke-Schaub 2013c]. The advantage of our approach, which uses individual

morphological charts transformable by the design team into a morphological overview, is that the design team's discussion begins after the preparation of the individual morphological charts. This allows each designer to develop his own interpretation and representation in relation to his specific discipline based knowledge and experience on the 'table'. This interpretation can then be compared with the interpretations by the other designers and after discussion formed into a morphological overview. In summary, this approach permits a more focussed discussion in the differentiation phase and integration phase of the McComb's mental model (see Fig. 2). It also enables to illustrate the mental model of the individual design team member as well as that from the design team as a whole.
Comparing the transformations in the different sessions (see Fig 4 left A to D) it shows the different processes that took place and the dominance within the teams by specific members. Quite remarkable is the dominance of the builder/contractor in session 2 team 2, resulting in the same amount of functions but less sub solutions. This clearly indicates the negative effect of this dominance. From Fig. 4a and 4c it follows that especially the architect has a positive effect on the outcome and has the highest effectiveness of all participants. This illustrates the different roles of the design team members in forming the design team's mental model. As such this enables to stress specific elements within an educational setting to balance design teams and strengthen input from all disciplines. More attention and training is needed for the other disciples to bring forward their ideas in the discussion about deciding what should be included in the morphological overview of the design team, the illustration of their mental model as a design team.

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