INTEGRAL DESIGN: TO COMBINE ARCHITECTURE AND ENGINEERING FOR A SUSTAINABLE BUILT ENVIRONMENT

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ABSTRACT
The traditional way of designing in the Building Industry has to change to meet the new demands for a sustainable built environment by society. In order to enhance team design in the most crucial phase for innovation, the conceptual design phase, a design method is proposed: Integral Design. Integral design was developed from a popular design method in the Netherlands, Methodical Design. This design method uses morphological charts which are transformed to a morphological overview by the design team as a framework to support the design process itself. The design method was tested in workshops held in cooperation with the Dutch Society of Architects and the Dutch society of building services engineers. It is important to bring in the specific knowledge and experience of the different engineering consultants (structural, building physics and building services) besides the architect from the very first moment of a design project to increase the possibilities for sustainable innovation. It proved that the design method applied in the workshops had a strong positive effect on the number of alternative generated by the design teams.

Keywords: sustainable design, morphological overview, multidisciplinary building design

1 INTRODUCTION
In modern history, design of buildings is seen as largely an individual's creative act (Habraken 2005) This is certainly the case for conceptual design phase, where architect is the one that lays down the vision of the whole building. Moreover, "the belief that a single designer should be in control of all levels of environmental form" (Habraken 2005, p.89) is even seen as a professional ideal.
The product which has the biggest impact on sustainability of humans are their buildings. The built environment uses 40% of all our energy for conditioning the buildings and 8 % of all our energy to be built. Sustainable building designs need to provide solutions for sustainability issues ranging from flexible use to renewable energy, energy reduction measures while maintaining and even increasing comfort level of the users. The European Directive 2002/91/EC requires therefore practitioners to provide buildings with design solutions that comply with minimum energy performance requirements, while safeguarding thermal comfort (Mazzeo et al 2008).
However there is a mixed performance in the realization of sustainability objectives, there are a number of key barriers hindering progress and as a result the process became more complex (Williams and Diar 2007). Sustainability is a real-world problem which cannot be solved by any one discipline alone (Dykes et al 2009). It requires multiple disciplines with a shared theoretical understanding and an agreed interpretation of knowledge according to Gibbons et al. 1994 (Dykes et al 2009). 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 (Joyce et al 2010), in a way that solves new problems or presents new solutions (Burt 2004, Rosenkopf & Nerkar 2001).
New approaches are needed to bridge the gap between the worlds of theory and practice in building industry which look at designing as a process in which the concepts of function, behavior and shape of artifacts play a central role (Vermaas & Dorst 2007). Such integral design approach can eventually lead to an integral process, team and method – all the required conditions for innovation of the end product; the building (Seppänen et al 2007). The building design process becomes more heterogeneous, with several diverse actors involved such as architects, engineers, contractors and clients. The different viewpoints imply a need for cooperation: a collaborative approach to the design process. These changes have led to a shift in the role of the architect in the building design process.

The former master builder with the responsibility for the totality has been reduced to merely an actor among others in the briefing and design phases of a complex project (Kjølle & Gustafsson 2007). Still architects have a larger influence on the crucial conceptual design decisions during the building design process and often act not as merely an actor but as conductor. Sustainability is a crusial issue for our future and architecture has an important role to direct sustainable development (Taleghani et al 2010).
The main body of the paper starts (Section 2) with the development of the Integral Design (ID) method: a design method that helps to merge the different perspective of all designers and engineers involved in the design process. The core of this method is the use of morphological charts. By combining morphological charts of each individual building design discipline, a morphological overview is created. This morphological overview represents the interpretation of the design task and the design knowledge within the design team related to the design task. The main aim of the ID-method approach is to improve conceptual design (the process level) in order to increase the potential for creation of innovative integral design concepts (the product level). To test the derived design method workshops for professionals, architects and engineers, in building design practice were held which are described in section 3. In section 4 the results are presented of the application of the ID-method within the workshops. A short discussion about the developed ID-method use to stimulate innovation in (building) industry given in section 5. Finally in section 6 some conclusions are given about the added value of the presented approach for innovation and knowledge transfer/creation in the Dutch building industry.

2 METHODOLOGY

In the early sixties due to problems with the quality of products and projects people started to investigate new design methods as a way to improve the outcome of design processes. Since then there was a period of expansion through the 1990s right up to day (Cross 2007), however there is still no clear picture (Horváth 2004, Bayazit 2004) and many models of designing exist (Wynn & Clarkson 2005, Pahl et al. 2006, Howard et al 2008, Tomiyama et al. 2009). In the Netherlands Methodical Design was a quite familiar design method (Blessing 1994, Zeiler and Savanovic 2009). The methodical design process of van den Kroonenberg is a framework application-independent principle with its connection to the general system theory and has some exceptional characteristics (Blessing 1994). Using the analogy with Systems theory van den Kroonenberg thought of a design process as a chain of activities, which starts with an abstract problem and results in a concrete solution. Methodical Design is problem oriented and distinguishes, based on functional hierarchy, various abstractions or complexity levels during different design phase activities. The essential element in this model is the design process. Methodical Design makes it possible to link these levels of abstraction with the stages and steps in the design process itself (Blessing 1994). This design method was extended into an integral design model by us by adding an evaluation step. The distinctive feature of the integral design method is the four-step pattern of activities (generating, synthesizing, selecting and shaping, see Fig.1, which occurs on each level of abstraction with the different phases of the design process.

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

2.1 MORPHOLOGICAL OVERVIEW

A distinguishing feature of Integral Design is the intensive use of morphological charts developed by Zwicky (1948) 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 sub solutions 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 (Ölvander et al 2008). Also the use of morphological chart is an excellent way to record information about the solutions for

the relevant functions and aid in the cognitive process of generating the system-level design solution (Wynn and Clarkson 2005). Morphological charts to visualize sub solution alternatives play a central role in the integral design approach for design teams. Each participant of a design team develops a full morphological chart from their own specialist point of view.

These individual discipline based morphological charts can be combined to one overall morphological chart, called morphological overview. The morphological overview of an integral design team process is generated, by combining in two steps the different morphological charts made by each discipline. Putting the morphological charts together enables to 'put on the table' the individual perspectives from each discipline about the interpretation of the design brief and its implications for each discipline. This enable, support and stimulates the discussion on and the selection of functions and aspects of importance for the specific design. In step one the functions and aspects are discussed and decides with are placed by the team in the morphological overview. After this in step 2 all participants of the design team can come up with their solutions for these functions and aspects, see Fig. 2.

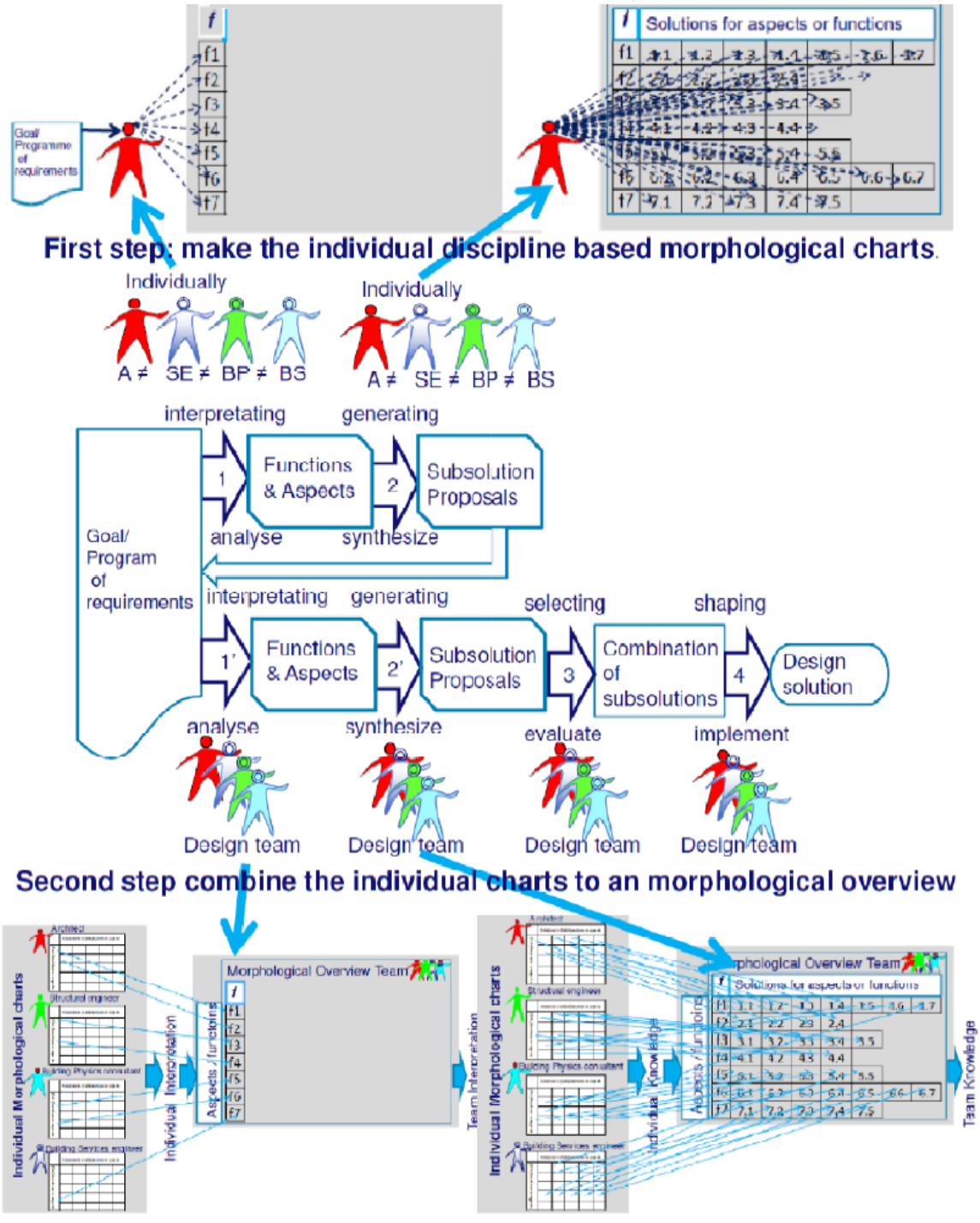


Figure 2. The steps to come from morphological charts to the morphological overview.

Although the use of morphological charts based on functional decomposition is quite common in mechanical engineering design, they are rarely used in a multi-disciplinary way besides the mechanical engineering domain. 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. The morphological charts made by each individual designer can be combined into a (team) morphological overview, after discussion on and the selection of functions and aspects considered important for the specific design. These are the most essential steps in the Integral Design process.

3 EXPERIMENTS

The next step was to test the approach of Integral Design with its use of the morphological overviews. After extensive experiments with different set ups, in which well over one hundred professionals participated (Zeiler et al 2005), it was concluded that a good way to test our design approach was a workshop setting for professionals. Therefore workshops were arranged as part of a training program for professional architects and consulting engineers (structural engineers, building services engineers and building physics engineers). 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 (Savanovic 2009). These design exercises were derived from real practice projects and as such were as close to professional practice as possible. The design tasks during the two days are on the same level of complexity and have been used in all workshops.

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 conceptual design 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.

To avoid a possible learning effect within a design team, after each session the participants were assigned to other teams so that no participants worked together more than once. Starting with the traditional sequential approach during the first two design sessions on day 1, which provide reference values for the effectiveness of the method (amount of integral design concepts), the perceived “integral approach” is reached through phased introduction of two major changes:

(1) all disciplines start working simultaneously within a design team setting from the very beginning of the conceptual design phase,

(2) the integral design model / morphological overviews are applied.

The second set up of the design sessions allowed simultaneous involvement of all design disciplines on a design task, which aimed to increase the amount of considered design functions/aspects. Additional application of morphological overviews during the set up of the third design session demonstrated the effect of transparent structuring of design functions/aspects on the amount of generated (sub) solution proposals. Additionally, the third setting provided the possibility of one full learning cycle regarding the use of morphological overviews. 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 the current configuration 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. Four different design set ups of participants and with or without Morphological Charts (MC) and Morphologic Overviews (MO) were tested.

Since 2005 together with the Dutch Royal society of architects (BNA) and the Dutch Association of Consulting Engineers (ONRI), 5 series of workshops were organized in which in total 107

experienced professionals, from both organizations, voluntarily applying to participate. The participants of each discipline were randomly assigned to design teams, which ideally would consist of one architect, one building physics consultant, one building services consultant and one structural engineer. Starting with a three day practice-like 'building team' concept, in which all disciplines are present within the design team from the start, the integral design method workshops have evolved to finally a two-day series. The average age of the participants, all members of eider BNA or ONRI was 42 and they had on average 12 years of professional experience.
In the workshops stepwise changes to the traditional building de sign process type, in which the architects starts the process and the other designer join in later in the process, are introduced in the set up of the design sessions, see Fig. 3.

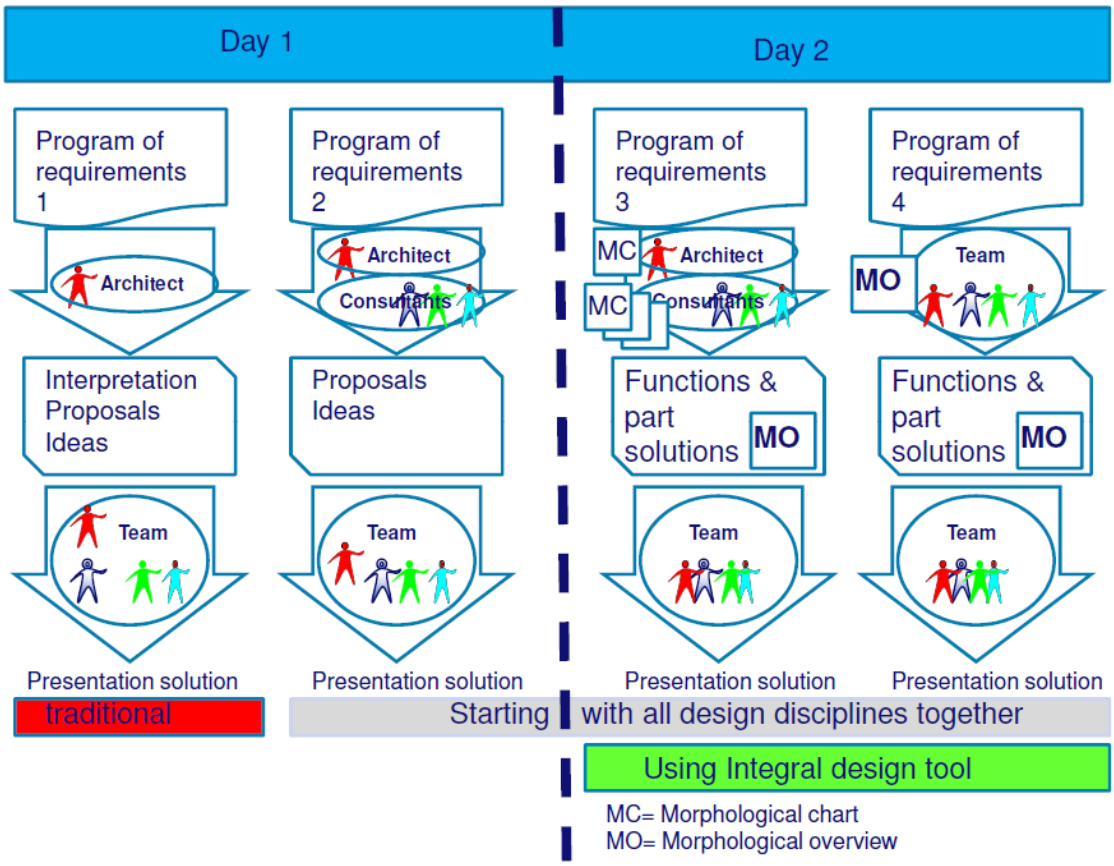


Figure 3. Workshops series, four different design settings of participants and the use of the integral design tools during the design sessions within two days

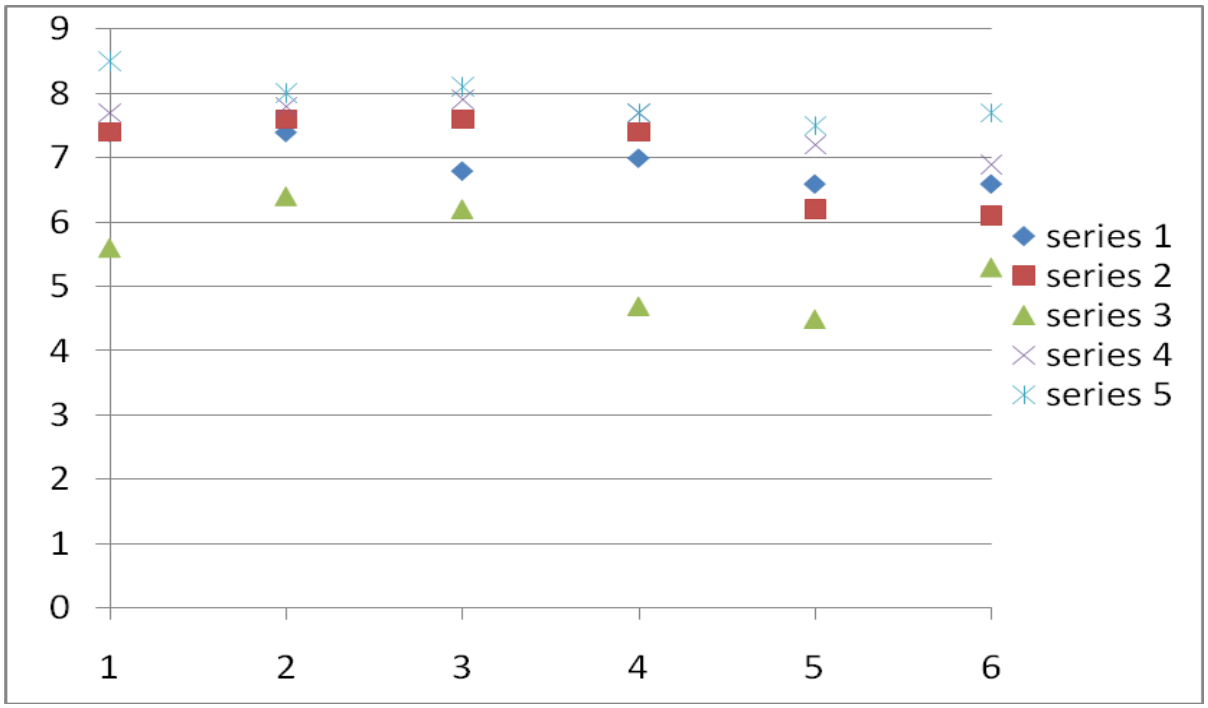
4 RESULTS

Here only a brief selection of all the results is given. More results and information is presented by Savanovic (2009). Since the workshops were designed for professionals in practice, great value was attached to their responses. Based on these results the workshop were adjusted. 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 and about the concept of the workshops themselves. The participants had to rate the answers, the average results was then transformed to a rating between 1 (very poor) to 10 (excellent), see table 1.
A practical aim of this research was to develop a working method that would allow architectural and engineering professionals to work in an integral team approach with the view to arriving at a more efficient design process and better design products. Ultimately, the measurable criteria to determine whether this aim has been met is the level of the acceptance of the method by the designers (BNA and ONRI professionals) involved in its development and use.
All workshop participants were asked to fill in questionnaires. The same questionnaires were used for all five workshops, which allowed for general comparison of the workshops series. The designers that were present during all design settings of the workshop they participated in were approached six

months after the sessions in order to get their 'second opinion', a post-evaluation. The response to post-evaluations was 45% compared to directly after the workshops 95%.

	series 1	series 2	series 3	series 4	series 5
Number participants	20	20	22	27	18
Percntage returned questionnaires	88%	96%	98%	96%	97%

Table 1. Overview Results Questionnaires Participants Workshop Series.



1 MO improves insight other disciplines
2 MO relevant for own discipline
3 MO helpfull for communication
4 MO positive effect design process
5 MO positive effect final design expect to use
6 MO in daily practice

Figure 4. Evaluation of the effects of Morphological Overviews in the workshops series

It shows from the results of the questionnaires that the participants of the workshops thought the use of morphological overviews improved the insight in the other disciplines, was of value to the communication and that it was positive for the increase of relevant alternatives within the design process.

Different set up for the workshops were tested but for the series 4 and 5 the final form of the workshops described herefore was used. A detailed comparison will now be given between settings 1 and 4 of the 5 teams from the final workshop series 5 in which 16 professionals participated. All teams worked on the same design tasks to be able to compare the outcomes of the design process from the different settings (Savanovic 2009). Fig. 6 shows the average number of aspects and sub solutions generated by all the teams in the two different settings 1 and 4, this clearly shows that, as expected, more aspects/functions were discussed and sub solutions were generated in setting 4 compared to setting 1.

From the analysis of the workshops it could be concluded that, the number of functions and aspects considered, as well as the number of subsolutions offered, was significantly increased by applying the Integral design method with its use of Morphological Overview. 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), see Fig. 5.

The comparison of design setting 1 and 2 presents the effect of introducing all the different designers from the start without using support. This led to a decrease of the number of aspects and subsolutions, indicating a less effective design process. This is inline with literature about brainstorm experiments (Nystad et al 2003), were they also found out that by just bringing together more designers the productivity doesnot increase compared with the results from individual sessions. The team has to have a kind of guidance, in our case the Integral design method.

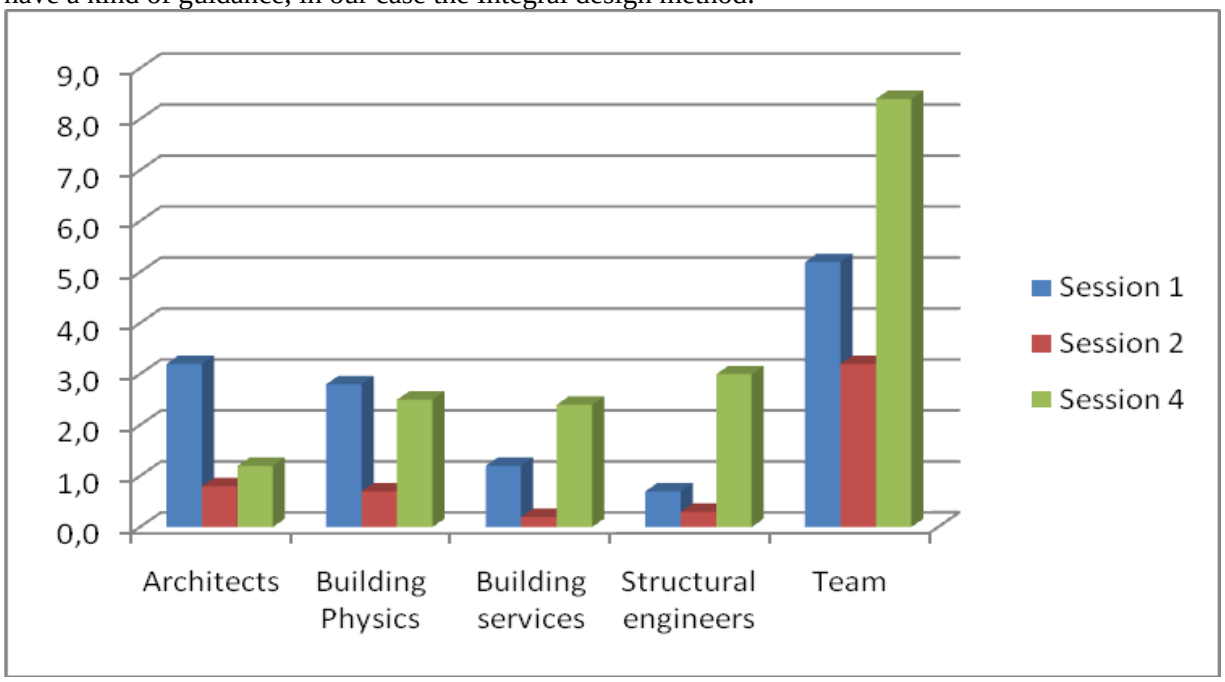


Figure 5. Average number of functions or aspects of team members during the different sessions of the last workshops series

The effect of the design intervention is different for each discipline par example there is a decrease of outcome for architects and building physics consultants but an increase of outcome by building services, structural engineers and for the design team as such, see Fig. 6.

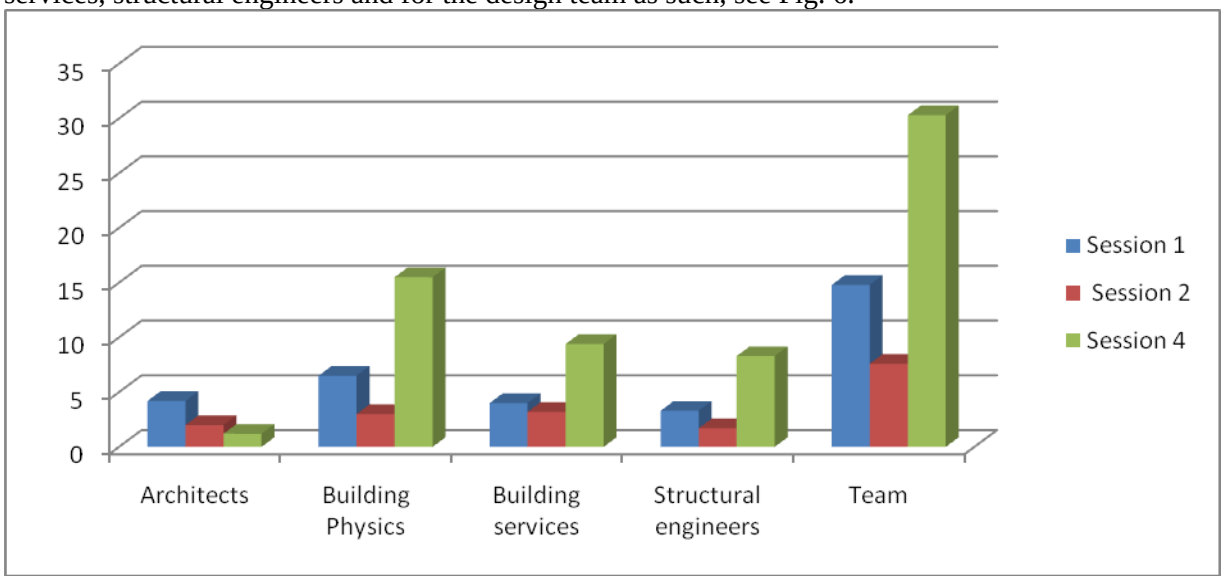


Figure 6. Average number of sub solutions of team members during the different sessions of the last workshops series

When comparing the overall results of sessions 1, 2 and 4 the difference between the different interventions can be seen, see Fig. 7, between session 1 and 2 the effect of starting working together from the first moment in the process and between session 1 and 4 the effect of working together from the first moment in the process but then with a supportive design tool.

Figure 7. Comparison of the number of aspects/functions and the number of partial solutions being generated by the design teams in design sessions 1, 2 & 4 of the final workshops series

5 DISCUSSION

To try to improve the current building design practice in the Netherlands 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 and as such has exceptional characteristics (Blessing 1994). This formed the basis for extension of the Methodical Design method into Integral Design. The idea of the Integral Design method was that it should be more suitable for other domains. To test the hypotheses the Integral Design method was used in the building design domain, were the complexity of design processes demanded new design approaches. The Integral Design method was used as a theoretical basis for structuring the design process in the Integral design project of the Dutch Technical Association of Building Services Engineers (TVVL) and Royal Society of Dutch Architects (BNA). This demonstrated that a workshop setting can be applied as 'training' for integral design, both in practice and education. Using it primarily as a learning tool, a workshop setting can at the same time serve to test the Integral Design method.

By using the morphological overview the design team has a more and clearer overview of the interpretations and possible solutions from each discipline, which can lead to synergy between the different disciplines. This in itself rendered the design process more efficient as it removed an unnecessary iteration, that is, the architect beginning the design task on his own before receiving input from engineering disciplines.

The activation of design team member's knowledge through a priming manipulation such as the use of morphological charts of morphological overviews leads to the generation of possibly generation of more (original) solutions. However there is a uncertain relation between quantity and qualilty. The most parsimonious interpretation of the quantity-quality relation is chance (Rietzschel et al 2007): each generated idea has an equal probability of being a good idea. Therefore, according to the laws of chance, the number of good ideas producced should increase in dependency of the total number of ideas produceed (Rietzschel et al. 2007). Still there is no simple linear relation between total productivity and the number of good ideas.

It is necessary to develope more support to designers for the morphologial analysis. Therefore morphological chart and morphological overviews are parts of the Integral design method which acts as supportive framework. Also it is necessary to know more about the black boxes of the individual team members'brains, for that Team Mental Models, once more completely developed, could prove supportive.

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 (Badke-Schaub et al 2010). 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 (Badke-Schaub et al 2010). In order to understand the present built environment, of which one of the imperatives is the unity of knowledge from design, engineering, financing, socio-cultural, etc. trans-disciplinary building design should embrace the concern between disciplines, across the different disciplines, and beyond all discipline (Ibrahim et al 2007). The trans-disciplinary approach is a framework for allowing members of a design team to contribute knowledge and experiences, collaborate with other members, and collectively determine the design that most would benefit the client (Ibrahim et al 2007).

Creativity and innovation are fundamental to the survival and advancement of society (Joyce et al 2010). Creative collaborations that cross disciplinary boundaries are essential to innovation and the occurrence of boundary spanning, where ideas from one domain, discipline or functional area are imported into another (Joyce et al. 2010), in a way that solves new problems or presents new solutions (Burt 2004, Rosenkopf & Nerkar 2001). 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 (Joyce et al 2010).

6 CONCLUDING REMARKS

At the TU Eindhoven an Integral Design method (ID-method) has been developed. In workshops with experienced professionals a first prototype of the ID-method was developed integrating four key elements: design team, design model, design tool and design setting. The ID-method was developed and tested in practice in cooperation with the Dutch society of Architects and the Dutch society of consulting engineers. In 2006 the Institute of Dutch Architects decided, based on the acquired positive results from the evaluations of the workshop participants, to include the ID-method in their Academy for permanent profession development. An ID-method course will be facilitated by the Dutch Society for Building Services Engineers and will start in second half of 2011. Through this the ID-design method stimulates innovation in Dutch building industry on an organizational and cultural level.

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