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BUILDING DESIGN WORKSHOPS FOR SYNERGY BETWEEN ARCHITECTURE AND ENGINEERING

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ABSTRACT
More and more building design involves multi-disciplinary design teams to support the growing complexity of the process. A supportive design approach is developed: Integral Design. This design method results in transparency of the design steps within the building design process. We regard these activities as the core elements of designing (design as process). Within the design process, the prescriptive methodology of Integral Design, especially its morphological charts transformed to a morphological overview, is used as a framework for reflection on the design process itself by the design team and their stakeholders (projectmanagers, clients). Morphology provides overview and helps to structure the communication and reflection between design team members and their stakeholders.

Keywords: Integral design, Architectural design synergy

1 INTRODUCTION
During the last years aspects of used technology for comfort and energy control within the building industry became more important as the demands to comfort and energy consumption became complex and strict. Effective design and effective construction are both necessary to produce high quality buildings and are therefore closely related. This process is initiated by the design task based on the need that has to be fulfilled and results in a description of the product. The architectural design process is complex and has a vague structure. The designer starts from an ill-defined problem and through different steps and stages progress has to be made up to a blueprint for a solution. The conceptual design stage is especially vague. It 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 (Aliakseyeu 2003). As the design proceeds, more information and detail are developed. Though there is little information at the early stages of design nearly all the important decisions have to be made at this time. There is an influence/information contradiction (den Hartog 2003), or design process paradox (Ullman 1992).
Traditionally the architect is the creator who makes designs and the engineer is the analyst and tester who optimizes and makes buildable those designs (Speaks 2008), but this has to change. To quote John Habraken, emerituius professor of MIT (2006); "*The very idea of "architecture' as a self contained and single centrered act does not apply to work in everyday environment*". No longer are buildings designed by an architect alone but a whole design team is needed to cope with the complexity and come up with the right solution. During building design processes synergy between the different disciplines involved in the design process is necessary to reach good designs. No longer is it sufficient to just merely solve the problems which arise at the level of detailing on the borderlines of disciplines. As complexity and scale of design processes in architecture and in building services engineering increase, as well as the demands on these processes with respect to costs, throughput time and quality, traditional approaches to organize and plan these processes may no longer suffice (van Aken 2005). Currently, cooperation between (Dutch) building design disciplines is unsatisfactory; better organization of building design process is apparently necessary (Friedl 2000).
There is a need to view all the different aspects of building design in a more integral way, resulting in an integral approach to building design to reach synergy between the designs disciplines involved instead of conflicts between them. This integral approach can lead to an integral process in which the design team with help of the design method can meet all required conditions of the end product and reach true synergy. Within a design team it is not enough just to engineer, engineers have to

participate as real designers too. Such a proactive approach needs support and the integral design approach could offer support to reach synergy between engineering and architectural design. This implies defining a process methodology that acts as a “bridge” between architectural elements such as shapes and material on the one hand, and the aspects of indoor climate issues such as overheating and ventilation on the other. Crucial point by using experiments, in relationship to the ‘theoretical’ model of the Design process, is the connection to a ‘realistic’ model which is part of the design-practice.

2 METHODS

The design process starts from making/reading the brief by the architect. To design is to formulate solutions, taking into account the targets to be achieved, the available resources and the prevailing constrains. In order to survey solutions, designers classify them based on various features. This classification provides means for decomposing complex design tasks into manageable size problems. An important decomposition is based on building component functions. The functional decomposition is carried out hierarchically so that the structure is partitioned into sets of functional subsystems and the decomposition is carried out until arrived at simple building components whose design is a relatively easy task. Design is essentially a decision making endeavour, where a significant portion of the progress towards each solution state can be made by application and/or heuristically based operations (Mijers & Phol 1992).

In the project description the needs are described in terms which designers can use to choose from among alternative solutions as rationally as possible. This indicates that there is also an amount of subjective interpretation involved. Therefore, design can be also viewed as a big black box: ‘needs’ form the input and ‘blue print solutions’ make up the output. The use of a black box is appropriate for determining the functions of the product to be designed. However, as a model of the design process it is hardly useful. In other words: the black box has to be opened.

Going back to the formulation of the design problem and the list of requirements is often an essential consequence of the gained insight into the true nature of the problem. The gained insight results in adjustment and expansion or sharpening of initial formulation of the design task.

Work done in later phases of the design process may change one’s understanding of the design problem and new information may become available. Therefore modification and refinement of the initial specification should be undertaken regularly. The design specification is best further developed in a strong interaction through successive iterative cycles, until design requirements and decision criteria fit one another. By introducing different levels of abstraction the designer can limit the complex design question to smaller sub-questions. The design task can be viewed on each individual level of abstraction. The emphasis at higher levels of abstraction lies on the problem definition phase and generation, while at lower levels of abstraction the emphasis is on developing details of the design product. Abstraction to us is the selective examination of certain aspects of a problem and helps the designer to decompose a complex design question into problems of manageable size. To quote Sim and (Duffy 2003); “Abstractions are more than simplifications of behavior and form; they are the result of cognitive decisions to ignore classes of behavior and portions of the design object. Useful abstractions must capture the important relations between behavior and form to enable designers to make good design refinements”.

As a result, designers use abstractions and models to focus on various characteristics of a design and to simplify the complex relationships between function and form and behavior (Sim and Duffy 2003). This abstraction leads to looking at designing as a process in which the concepts of function, behavior and structure of artifacts play a central role (van den Kroonenberg and Siers 1992).

In the Netherlands such a model was developed in the early 1970s: a prescriptive design model to teach design to mechanical engineering students at the University of Twente (van den Kroonenberg 1974). Called the methodical design model, it was based on the combination of the German (Kesselring, Hansen, Roth, Rodenacker , Pahl and Beitz) and the Anglo-American design schools (Asimov, Matousek, Krick) (van den Kroonenberg 1992). The approach by van den Kroonenberg is similar to the Integrated Product Development (IPD) by Andreasen (Andreasen and Hein 1987, Buur and Andreasen 1989). This design model was choosen because; “it is one of the few models that explicitly distinguish between stages and activities, and the only model that emphasis the recurrent execution of the process on every level of complexity (Blessing 1993, p.1398)”. Especially the horizontal dimension is not strongly represented in other familiar design models and thus tends to be forgotten (Roozenburg and Cross 1991, p. 216); “not so much by its authors (see for instance Pahl and Hubka) but by its users and, above all, its critics, leading to faulty arguments and wrong interpretations of the model." This in the Netherlands familiar model (Blessing 1994) was extended into an integral design model by us by adding an evaluation step. So a distinctive feature of the integral design model is the four-step pattern of activities (generating, synthesizing, selecting and shaping, see figure 1), that occurs on each level of abstraction with the design process.

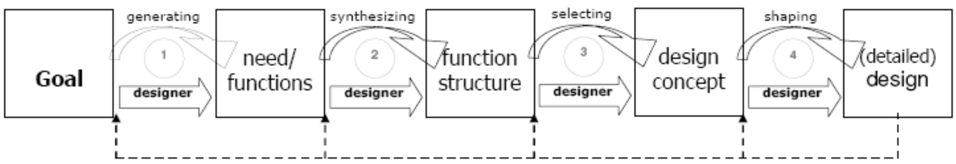


Figure 1. The four-step pattern of Integral Design with possible iteration loops

The major difference between the integral design matrix and other familiar models is the shaping step, in which the design is 'shaped', gets more concrete and transforms as such in a lower level of abstraction. The design activities sequence in integral design is: define/generate, analyze/synthesize, evaluate/select, and implement/shape. If compared with familiar models e.g. the basic design cycle of Roozenburg and Eekels, 1995 (analysis, synthesis, simulation, evaluation and decision) the difference is in the implementation and shaping of the design into a lower level of abstraction and as such a focus on the connection between the horizontal dimension and the vertical dimension of the design model. The row of the integral design matrix provide the different issues, functions and aspects, to be solved in the design process, based on the process stages distinguished by methodical design (Problem definition, Working principle and Shaping phase) with a new added process stage: the selecting phase. Once completed, the integral design matrix contains a description of the design process for a specific design task. The description is depending on the rationale applied and may not be chronological: the matrix structures the (intermediate) results of the process independently of the sequence in which they were generated (Blessing, 1993, p. 1398). This makes it possible to focus on the selecting phase and to integrate the opinions of others outside the design team more easily. The design process becomes more transparent and this increases the possibility to reach synergy between the different disciplines and/or designers involved in the design process.

2.1 Function strategy and morphological charts

Using function/aspect-oriented strategy, the integral design model allows various design complexity levels to be separately discussed and generated (sub) solutions to be transparently presented. Subsequently, the model makes it possible to link different abstraction levels with the phases in the design process, while maintaining a basic four-step design cycle (generate, synthesize, select, shape) recognizable within each phase. The functions required for working with the model can be regarded as what a design is supposed to fulfil: the intended behaviour or intended characteristics of the object. The definition of functions during the interpretation of a design task makes it possible to assess the client's needs on higher, but more workable, abstraction levels than the program of requirements usually provides. Based on definition of functions, various design complexity levels can be separately discussed and, accordingly, possible solutions generated. This way interaction with and the interpretation of the design brief is aided.

Functions have a very significant role in the design process. Generally, designers think in functions before they are concerned with details. During the design process, and depending on the focus of the designer, functions exist at the different levels of abstraction. An important decomposition is based on functions. Function-oriented strategy, preferred by experienced designers (Fricke 1993), allows various design complexity levels to be separately discussed and, subsequently, generated (sub)solutions to be transparently presented. The design process can be even more structured by giving an overview of the considered functions and aspects and their solution alternatives, this is called a morphological chart (Zwicky & Wilson 1967), see figure 2.

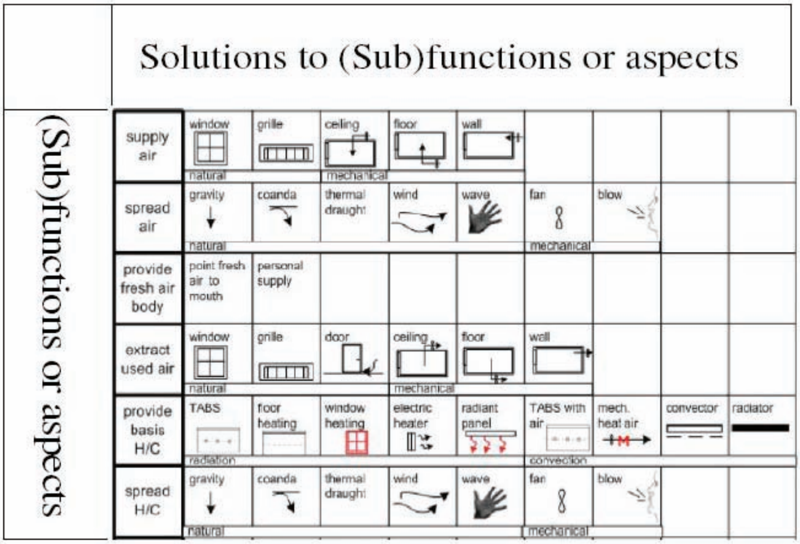


Figure 2. The morphological chart within the Integral Design method

The term morphology comes from antique Greek and means the study of shape, form or pattern, i.e. the shape and arrangement of parts of an object, and how these "conform" to create a whole or Gestalt (Ritchey 1998). Morphological charts were developed by Fritz Zwicky in 1947 (Norris 1963) as a tool for investigating the totality of relationships contained in multi-dimensional, usually non-quantifiable problem complexes (Ritchey 1998).

On the vertical axis of the morphological chart the required functions, sub-functions or aspects are placed. The purpose of the vertical list is to try to establish those essential functions or aspects that must be incorporated in the product, or that the design has to fulfill. These are expressed in rather abstract terms of product requirements or functions. On the horizontal axis possible sub-solutions for these functions or aspects are given. The morphological chart gives an overview of aspect elements or sub-solutions that can be combined together to form overall solutions, see figure 3.

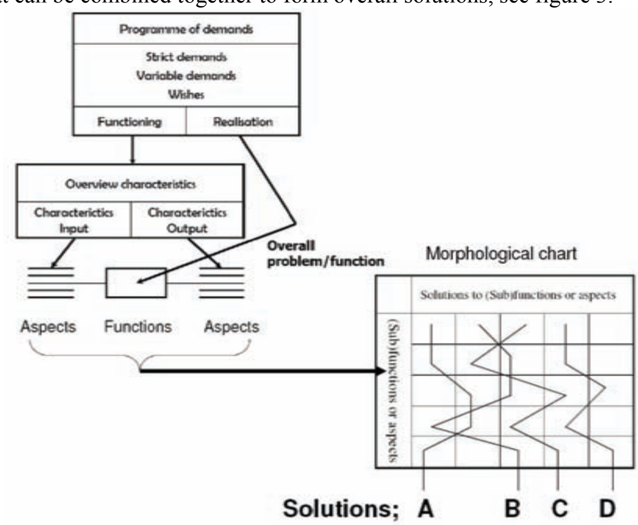


Figure 3. Programme of demands as input for the morphological chart, sub functions on the vertical axis and the possible solutions as combinations of elements on the horizontal rows of the matrix.

2.2 Morphological overviews

The focus within integral design is on all that is essential to completeness, from all design disciplines nothing essential should be lacking. By using morphological charts each discipline can look individually for the required completeness: if all necessary functions and aspects are listed. The morphological approach widens the search area for possible new solutions (Cross 1994). It may help to discover new solutions, which may not be so evident and could have been overlooked. It has also definite advantages for communication and for group work (Ritchey 1998).

General morphological analysis was developed by Fritz Zwicky (Zwicky & Wilson 1967) as a method for identifying and investigating the total set of possible relationships or configurations contained in a given problem complex (Ritchey 1998). Morphology provides a structure to give an overview of the considered functions and aspects and their solution alternatives. Transforming the program of demands into characteristics for input and output (aspects) and formulation of the different relations between input and output (functions) to fulfill, leads to the construction of a morphological chart, see figure 4, symbol 1.

In 2004 a research project started using Integral Design methodology as a model for structuring knowledge of the design team members. Especially morphological charts to visualize solution alternatives play a central role. A morphological overview is generated by combining the different morphological charts made by each discipline after discussion on and the selection of functions and aspects of importance for the specific design (figure 4) as well the relevant solutions to the agreed sub functions or aspects(figure 5) . Such a morphologic overview can be used by the designers to reflect on the results during the different design process stages.

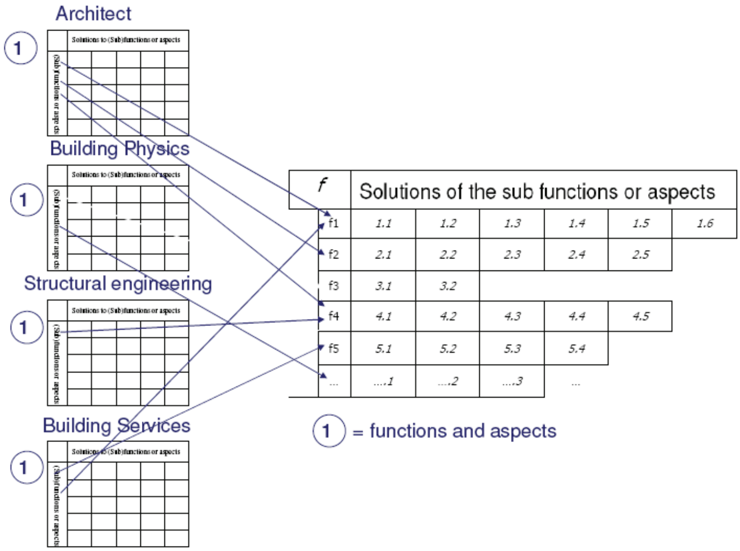


Figure 4. Building the morphological overview; Step 1; The Morphological overviews show the agreed functions and aspects (1)of the different morphological charts.

Such a morphologic overview can be used by the designers to reflect on the results during the different design process stages. Although the use of functional description and morphological charts is common practice in mechanical engineering design, they are rarely used in a multi-disciplinary way besides engineering. Especially the input of ‘soft’ aspects adds a new dimension to the strict functional approach of traditional morphological chart. The morphological overview makes it possible to change from “Form follows Function ” (Sullivan 1896) to a new way of conceptualizing design as a professional practice in which design is making sense of things (Krippendorf 2006): hard and soft things. Replacing an individual designer in a ‘reflective practitioner scenario’ by a design team increases the chance of achieving integration through concentration on every relevant aspect of design task at hand. The relevancy of aspects is subjectively decided by design teams themselves, by continuously (re)interpreting design brief and design proposals. The objectivity / transparency is reached in presentation of the team interpretations, explaining their interconnection instead of why and how behind each individual separate interpretation cases.

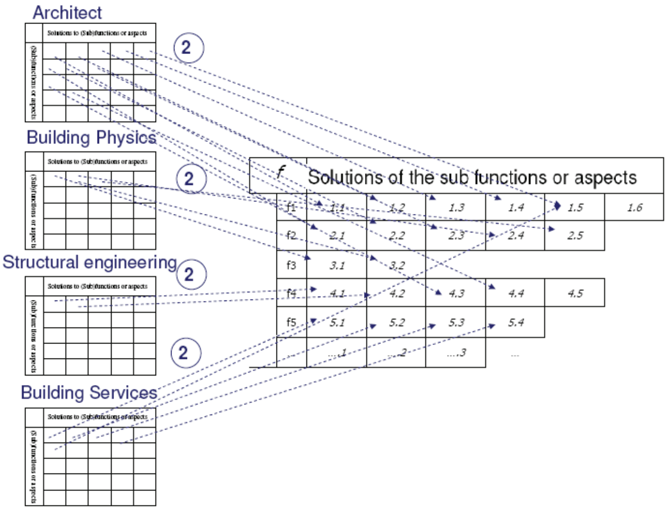


Figure 5. Building the morphological overview; Step 2: The Morphological Overview with the agreed on sub solutions (2) from the separate morphological charts

The above described approach was tested in a series of 5 workshops. 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.

3 EXPERIMENTS

Since 2005 together with the Dutch Royal society of architects (BNA) and the Dutch Association of Consulting Engineers (ONRI), we organized 5 series of workshops with 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. Over the past four years the Integral Design method, with its Morphological Overview as a major design tool, was tested in a series of 5 workshops, these typically include around twenty participants and lasted for two or three days. 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. A total of 108 designers participated in a five workshop series, in which 74% of the designers were present during all days. 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. The analysis of the workshops and the feedback led to a final setting of the workshops. This was applied in two workshops series to compare of the results.

4th and 5th workshop series: Final workshop setting

The experiences of workshops series 3 led to adjustments for the following workshops series 4 and 5. The 4th workshop was held in May 2007 and the 5th workshop was held in February 2008. In the current configuration (Figure 6) stepwise changes to the traditional building design 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. Starting with the traditional sequential approach during the first two design sessions on day 1, which provide reference values for 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 allows simultaneous involvement of all design disciplines on a design task, aiming to influence the amount of considered design functions/aspects. Additional application of morphological overviews during the set up of the third design session demonstrates the effect of transparent structuring of design functions/aspects on the amount of generated (sub) solution proposals. Additionally, the third setting provides the possibility of one full learning cycle regarding the use of morphological overviews.

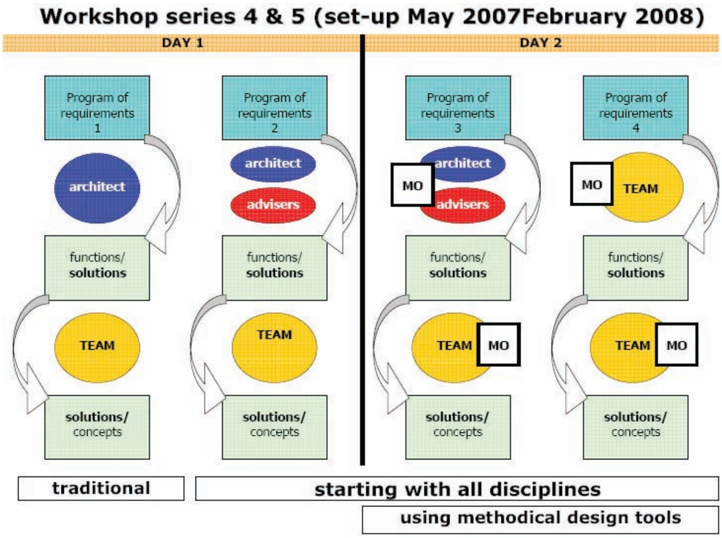


Figure 6. Workshops series 4 & 5, four different design set ups of participants and Morphologic Overviews (MO) during the design sessions within two days

4 RESULTS

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 were asked to fill a questionnaire and had to rate the answers, the average results was then transformed to a rating between 1 (very poor) to 10 (excellent), see table 2.

	series 1	**series 2**	**series 3**	**series 4**	**series 5**
Number participants	20	20	22	27	18
Percentage returned questionnaires	*88%*	*96%*	*98%*	*96%*	*97%*
	average rating	*average rating*	*average rating*	*average rating*	*average rating*
MO increases relevant alternatives	6,2	7,3	5,7	7,8	7,9
MO helpful for communication	6,8	7,6	6,2	7,9	8,1
MO positive effect design process	7,0	7,4	4,7	7,7	7,7
MO positive effect final design	6,6	6,2	4,5	7,2	7,5
Expects to use MO in daily practice	6,6	6,1	5,3	6,9	7,7

Table 2. Overview results questionnaires participants workshop series

The results of the questionnaires indicate that the participants of the workshops thought the use of morphological overviews of value to communication and the number of relevant alternatives within the design process

Participants of the five series workshops were approached six months after their workshop participation in order to get their 'second opinion' on the proposed approach and to assess the effects that the Integral Design method has had on their practices. Only the reactions from designers who participated during all design sessions of a series were taken into account. The results of the most relevant questions related to the integral design method and morphological overviews are given below in table 3.

Table 3. Ratings by participants' workshops series 1 to 4 after a working period of six month's

	architects	BPC's	BSC's	SE's	Total
Number participants	24	22	19	8	73
Percentage returned questionnaires	67%	68%	58%	63%	66%
Rating workshop after 6 months, (1-10)	7,1	7,1	6,5	7,6	7,0
Did you use morphological overviews in the last six months? (% yes)	49	35	32	60	41
Is use of morphological overviews relevant for your discipline? (% yes)	63	60	65	84	65
Is it appropriate to stimulate use of morphological overviews? (% yes)	68	68	62	92	69

When we compared the results of the questionnaires after six month's with those directly after the workshops were held, there were some differences, see table 4 and figure 7.

Table 4. Number returned questionnaire

	Direct after Series	After 6 months
Number participants	108	73
Percentage returned questionnaires	94%	66%

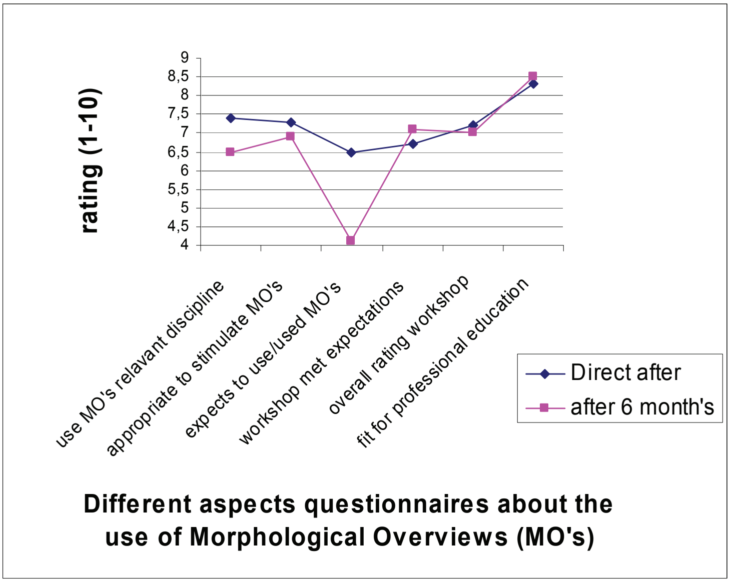
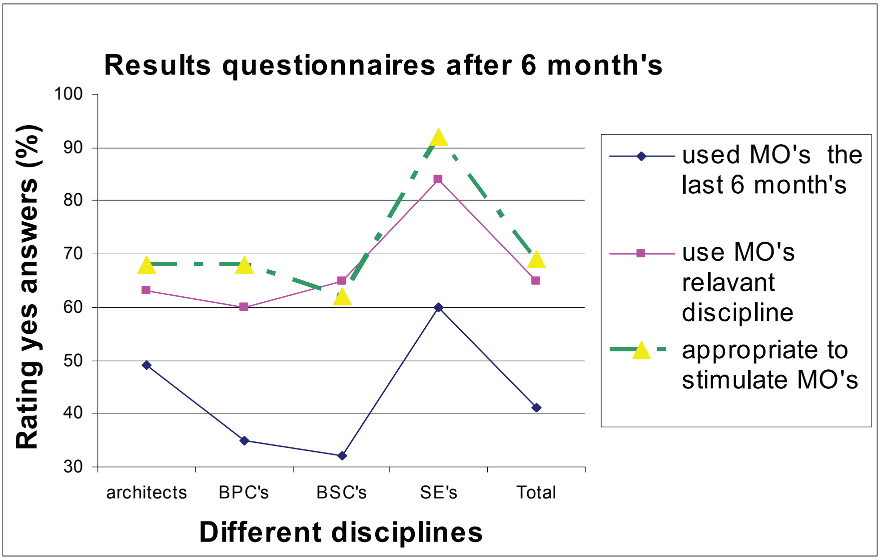


Figure 7. Comparison between average ratings direct at the end and after a working period of six month's of the professional workshops

Comparing the results of the questionnaires direct at the end of the workshop and after a period of 6 month's there is only one remarkable difference in rating, the use or expected use of morphological overviews, 6,5 compared to 4,1. Remarkable is the almost same difference between expected use and real use of morphological overviews of all the different disciplines of almost 25%., see figure 8. Still on average 40% of the participants used morphological overviews in their practice. What we can see is the relative low score for building physics consultants and building services consultants. They both normally come in a later phase of the design process often after the conceptual design phase. This meant that they could not introduce the morphological overview anymore. Also most of the participants were working in large ongoing projects which already were past the conceptual design phase. That might be the explanation of the low score.



BPC = Building Physics Consultants
BSC = Building Services Consultants
SE = Structural Engineering consultants

Figure 8. Results questionnaires on different aspects of the use of MO's of workshops series 1 to 5 after a working period of six month's

When asked if they think the workshop approach is suited for the permanent educational program the participants are after the period of 6 month's even a bit more positive as compared to direct after the workshops; 8,5 compared to 8,3. This indicates, in contrast to the low application of the Integral Design method by the professionals in practice, the added value of the approach to the practice of building design to the professionals.

5 DISCUSSION

To stimulate knowledge exchange during design processes a design support tool was tested in different workshops series with professionals within the setting of Reflective Practice (Schön 1983). To use human subjects in laboratory experiments to study design theory provide some insight. However, extending results from laboratory experiment to conclusions for the engineering practice is a risk. The effect of Macro cognition describes the differences in cognitive functions performed in natural – versus artificial, laboratory – settings. The real-world setting requires activities in ways that artificial settings can rarely simulate. Schön (1987) has proposed a practicum as a means to 'test' design(ing). Where a practicum is" a virtual world, relatively free of the pressures, distractions, and risks of the real one, to which, nevertheless, it refers (Schön 1987, p.37)". In Schön's practicum a person or a team of persons has to carry out the design. A practicum can asses a design method and the degree to which it fits human cognitive and psychological attributes (Frey and Dym 2006).

Crucial is the simulation of the 'typical' design situation. A workshop can be seen as a specific kind of practicum. It is a self-evident way of working for designers that occurs both in practice as during their education. As such a workshop provides a suitable environment for testing the approach. Besides full design team line-up there are a number of other advantages of workshops with regard to standard office situations, while at the same time retaining practice-like situation as much as possible. Workshops make it possible to gather a large number of professionals in a relatively short time, repetition of the same assignment and comparison of different design teams and their results. Never the less the workshops are a virtual world; "contexts for experiment within which practitioners can suspend or control some of everyday impediments to rigorous reflection-in-action (Schön 1983 p. 162). Schön refers further to the dilemma of rigor and relevance in professional practice, there is a choice to stay on the high, hard ground ("A high, hard ground were practitioners can make effective use of research-based theory and technique") , or to descend to the swamp ("a swampy lowland where situations are confusing") and engage the most important and challenging problems? (Schön 1983 p. 42).
Design team arrangement is the crucial element. To be able to compare different types of design processes, while at the same time excluding team development aspects (Tuckman 1965), the same design teams are not observed during the two workshop days, instead the average results of each design setting of all participating teams are compared. For each setting the arrangement of design team members is changed (although all design teams are composed out of the same group of participating designers). The only rule is that no two designers can be in the same team twice. The focus is on the comparison of the same activities within different types of design processes. The sequence of used design settings is of utmost importance. Reverse or mixed order is not possible because learning effects would not allow for valid comparison of results (Herzog, 1996). This is in practice different as the design team stays the same during the design process and learns during the process.
Replacing an individual designer in a 'reflexive practitioner scenario' by a design team increases the chance of achieving integration through concentration on every relevant aspect of design task at hand. The relevancy of aspects is subjectively decided by design teams themselves, by continuously (re)interpreting design brief and design proposals. The objectivity / transparency we look for is in presentation of their interpretations, explaining their interconnection instead of why and how behind separate interpretation cases.
The result of the questionnaires showed that the Integral Design workshops with its morphological overviews as major design tool, proved to be supportive to the experienced professionals from BNA, Dutch Royal society of architects and ONRI, Dutch society of engineering consultants. Although the outcome has no strict statistical validity and therefore the empirical evidence is not significant, never the less the out come of the questionnaires indicates it value. Strict statistical approach are hard to apply to this kind of research as it is very difficult to get participation of expensive experience professional who have always a heavy workload and are also on time pressure within their projects.
Far more important 'evidence' is the fact that the experiences of participating architects from BNA with the workshops Integral design were so good that since 2007 the workshops have become part of the permanent professional education program of BNA. An additional 'proof' for success is the fact that the largest Dutch building services consulting company asked us to provide training for their employees within the company, based on the concept of the workshops. This was after several employees of this company had participated in the professional workshops. This workshop was held in company on March 31, 2008. Sixteen professionals attended this workshop and their overall rating of appreciating was 7.5 on a 1-10 scale. So we presume that by using our integral design workshops with the use of morphological overviews, we give professional a useful design method for the multi-disciplinary design problems they are facing in practice. We think that this is the best prove of the practical value of our presented approach.

6 CONCLUSION

New approaches in architectural management are needed which look at conceptual designing as a knowledge development process that needs to be supported with appropriate tools. This article provides an insight into how morphological overviews can be used as a design support tool within the building design process. Through visualization of contributions within a design team, morphological overviews can show how (integral) design concepts are emerging within design teams.

The focus in this paper was on the implementation of the Integral Design method in a “learning by doing” workshops approach developed throughout 2005-2008 and tested in 5 series of workshops in which professionals from BNA (architects) and ONRI (consultants) participated.
The experiences of the workshops for multidisciplinary professional design-teams led to the following conclusions;
- workshops are an effective tool to couple practice / research / education;
- the ‘learning by doing’-principle is effective approach in professional education
- morphological overviews as a design tool from the Integral Design method for multi-disciplinary design teams helps to structure and develop knowledge of design team members and is a necessary supplement to develop / effectuate the integral approach / integral design.
- implementing the new Integral Design approach is only practically possible at the beginning of a project

By structuring design (activities) and communication between design team members, morphological overviews form the basis for reflection on the design results; both by the design team members themselves and in discussion with external parties such as the project manager. Through the application of the integral design method each step within the design process becomes transparent, which makes it possible to reflect on all design steps. Potentially this makes it easier for to manage these design steps to reach the necessary synergy between architecture and engineering within the building design process.

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