Integral design method in the context of conceptual sustainable building design

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Abstract

Global warming, shortage of fossil fuel and rising energy prices are endangering humanity. The built environment is responsible for a large part of the energy use and waste production. Traditional building design approaches essentially lead to redesign and optimization, whereas to meet the unique challenges for sustainability in the present day built environment, we need to go further and generate new concepts and knowledge that represent the necessary conditions to arrive at new sustainable design solutions.

This research set out to develop a method to create a more integral process that would create the opportunity to introduce a greater variety and amount of design knowledge from the outset of the conceptual design phase. The approach was tested by using series of workshops in which more than 100 experienced professionals participated. The Integral Design method [ID-method] developed here, given the right cultural environment, may in time lead to the generation of new building concepts that will allow us the opportunity to move beyond redesign and optimization. The necessity of concept creation is shown by C-K theory that 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.

Keywords

Integral Design, morphological overview, C-K theory, workshops

Many factors influence the sustainability of the built environment, however, man-made climate change and the measures that are needed to counteract such change seem to be by far the main problems of our time. To understand the impact of building design on the environment, recent research has shown that 40% of the total energy output of The Netherlands is consumed by the built environment, and this figure rises to 70% when social services such as healthcare are included [Uitdenbogerd 2007]. The fact that these rather worrying figures are the result of current building design approaches underlines the need for new, creative approaches that can achieve better results.

Therefore there is a clear necessity to better integrate comfort and sustainable energy systems in buildings [Opstelten et al 2007]. It is our belief that this can best be achieved by rejecting current design practice, and by organising relevant disciplines into functional, mutlidiscplinary design teams.The unsatisfactory cooperation between building design disciplines has resulted in calls for better organization of the design process [Friedl 2000, Wichers Hoeth and Fleuren 2001]. These calls gain more importance when we consider the increased complexity in current design processes arising from, amongst other things, growing sustainability demands. In this context, traditional approaches to organize and plan these complex processes may no longer suffice [Van Aken 2005]. First and foremost, a method needs to be developed to allow other, largely engineering, building disciplines to be integrated into the design process from the outset in a meaningful way. This re-evaluation of the design process and the individual disciplines within it should facilitate the inclusion of all relevant team members at the outset and give proper recognition to the influence their knowledge and input has on the final design. The standpoint in this research is that a more integral process will not only improve the design process, it will also create the opportunity to introduce a greater variety and amount of design knowledge from the outset of the conceptual design phase.

Methodology

In the early sixties design became an international concern. In the United Kingdom the Feilden Report concluded that design was of paramount importance and asked for more effective design management, more attention to customer requirements and asked for more cooperation in design teams [Blessing 1994]. The origins of new 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 [Cross 2007]. However, in the 1970s came the rejection of design methodology by even some of the founding fathers themselves, such as Alexander and Jones. Fundamental issues were raised and design problems were characterized as 'wicked' problems, un-amenable to the techniques of science and engineering. This resulted in a proposal for a new generation of methods by Horst Rittel, moving away from attempts to optimize and towards recognition of satisfactory or appropriate solutions [Simon 1969]. In the 1980s engineering design methodology of the systematic variety developed strongly. A series of books on engineering design methods began to appear; Hubka [1980], Pahl and Beitz [1984], Cross [1984] and French [1985]. In fact, after the risen doubts of the 1970s, the 1980s saw 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 [Cross 2007]. Still there is no clear picture [Horváth 2004, Bayazit 2004] and many models of designing exist [Wynn & Clarkson 2005, Pahl et al. 2006, Howard et al 2008].

Even though design undoubtedly includes stretches of 'normal' ill-structured problem solving [Dorst and Rooyakkers 2006] any model or description method that tries to reduce design to ill-structured problem solving is bound to miss important aspects of the design activity [Hatchuel 2002]. Recognizing the fact that design is not a scientific or merely a problem solving activity, we wondered if any of the existing and largely neglected prescriptive design methods could help us to understand design by using them for research, rather than [as originally intended] for design activities. The motivation behind this idea was that, being developed on the basis of a scientific approach to designing, these prescriptive design methods 'automatically' meet the requirements for being methodical – one of the key characteristics of valid design research [Cross 2002]. We choose Methodical Design as developed by van den Kroonenberg as a starting point, as it is based on a synthesis of the German and Anglo-American design models of the mid seventies and using the analogy with Systems theory [Zeiler and Savanovic 2009b]. Within Methodical Design the design process is thought of as a chain of activities, which starts with an abstract problem and results in a concrete solution [Blessing 1994].

Morphological overviews within Integral Design

Starting from the prescriptive model of Methodical design a method 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 [Zeiler and Savanovic 2009a, 2009b]. Methodical design was chosen as a starting point of development because it has exceptional characteristics [Blessing 1994]. The Integral Design model, an adapted model of Methodical Design, allows various design complexity to be separately discussed and generated [sub] solutions to be transparently presented.

A distinguishing feature of Integral Design is the intensive use of morphological charts to support design activities in the design process. Morphological charts were first used by Zwicky [Zwicky 1948]. By using morphological charts each discipline can look for all the necessary functions and aspects decomposed from the program of demands. All of the design team members have to come up with their interpretation and possible solutions to the design task. On the vertical axis of the morphological chart the required functions, sub-functions or aspects are recorded. 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 fulfil. 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 solution proposals, see Fig. 1 combinations A, B and C. The proposals can be presented to the client and discussed. After which a decision can be made to proceed further or to do a backward iteration step in the design process.

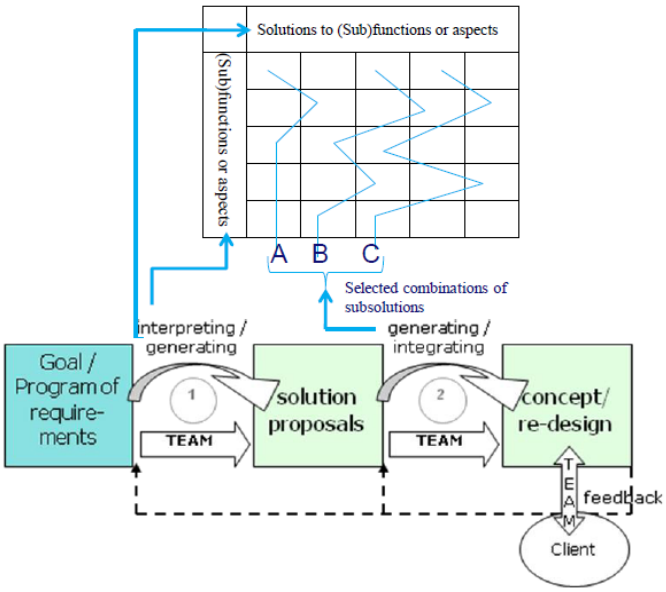


Figure 1: Program of demands as input for the morphological chart, sub functions on the vertical axis, the possible solutions as combinations of elements on the horizontal rows of the matrix. There is a possibility for feedback by the client as well as possible backward iteration loops.

As the morphological chart allows every designer to immediately see the results, they can discuss aspects that are unclear to them. The morphological charts made by each individual designer can be combined into a [team] morphological overview. The whole process is done in two steps: first the functions and aspects are discussed and then the possible related solutions see Fig. 2.

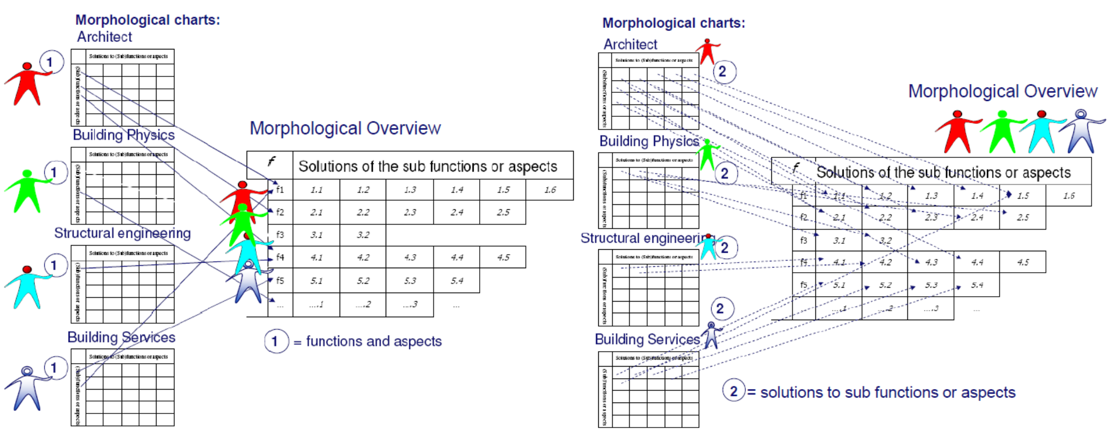


Figure 2: Building the morphological overview; Step 1; The Morphological overviews show the agreed functions and aspects [1] of the different morphological charts. Step 2: The Morphological Overview with the agreed on sub solutions [2] from the separate morphological charts

A morphological overview is generated [see Fig. 2] 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. Such a morphologic overview can be used by the designers to reflect on the results during the different design process stages. The advantage of this approach is that the discussion begins after the preparation of the individual morphological charts. As each designer uses his own interpretation and representation, in relation with his specific discipline based knowledge and experience, this gives an overview of different interpretations of the design brief resulting in a domain specific morphological chart from each design team member. 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 part solutions from the different disciplines. Morphological charts play a central role in facilitating the visualization of solution alternatives. Although the use of functional description and morphological charts is common practice in mechanical engineering design, there is scant evidence of their use outside of engineering or in a multi-disciplinary context. Within the approach described here, the possible input of 'soft' aspects adds a new dimension to the strict functional approach of a traditional morphological chart.

C-K theory

Pragmatic views of design as well as existing design theories [Yoshikawa 1981, Suh 1990, Gero 1996, Braha and Reich 2003] define design as a [dynamic] mapping process between required functions and selected structures [Hatchuel and Weil 2008]. Hatchuel and Weil argue that dynamic mapping is not sufficient to describe the generation of new objects and new knowledge, which, according to them, are distinctive features of design. Their statement that "there is no design if there are no concepts" [Hatchuel and Weil 2003, p.5] underpins the logic of C-K theory and of the present research. Generally speaking, design thinking is a creative process based around the transformation of needs into solutions. In this process existing knowledge and information about the actual needs of the principle forms the basis to work from. This often has to be transformed into new unknown concepts if solutions based on existing knowledge are not adequate. So, in this case, we have to develop from the known the unknown. As such we can make the distinction between the known [knowledge] and the unknown [concepts]. This distinction determines the core propositions of C-K theory [Hatchuel and Weil 2007].

Assuming that design thinking is related to design knowledge, and that knowledge is often something implicit, the definition of design by C-K theory [Hatchuel and Weil 2009] allowed us to approach design concepts as indicators of design thinking. 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. Within this research, in the case of a multidisciplinary building design team, the available knowledge within this team represents space 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" [Hatchuel and Weil 2002, p.11], all explicit representations of a design team's knowledge are considered to form part of space K. The overview of this knowledge is captured using morphological design tools. 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, see Fig. 3. In this thesis the former possibility is explained as leading to 'redesigns' [RE], while the latter leads to 'integral design concepts' [ID]. Ultimately, evaluation of RE-design can only result in the same object-design-knowledge, while from ID-concepts new object-design-knowledge can be created.

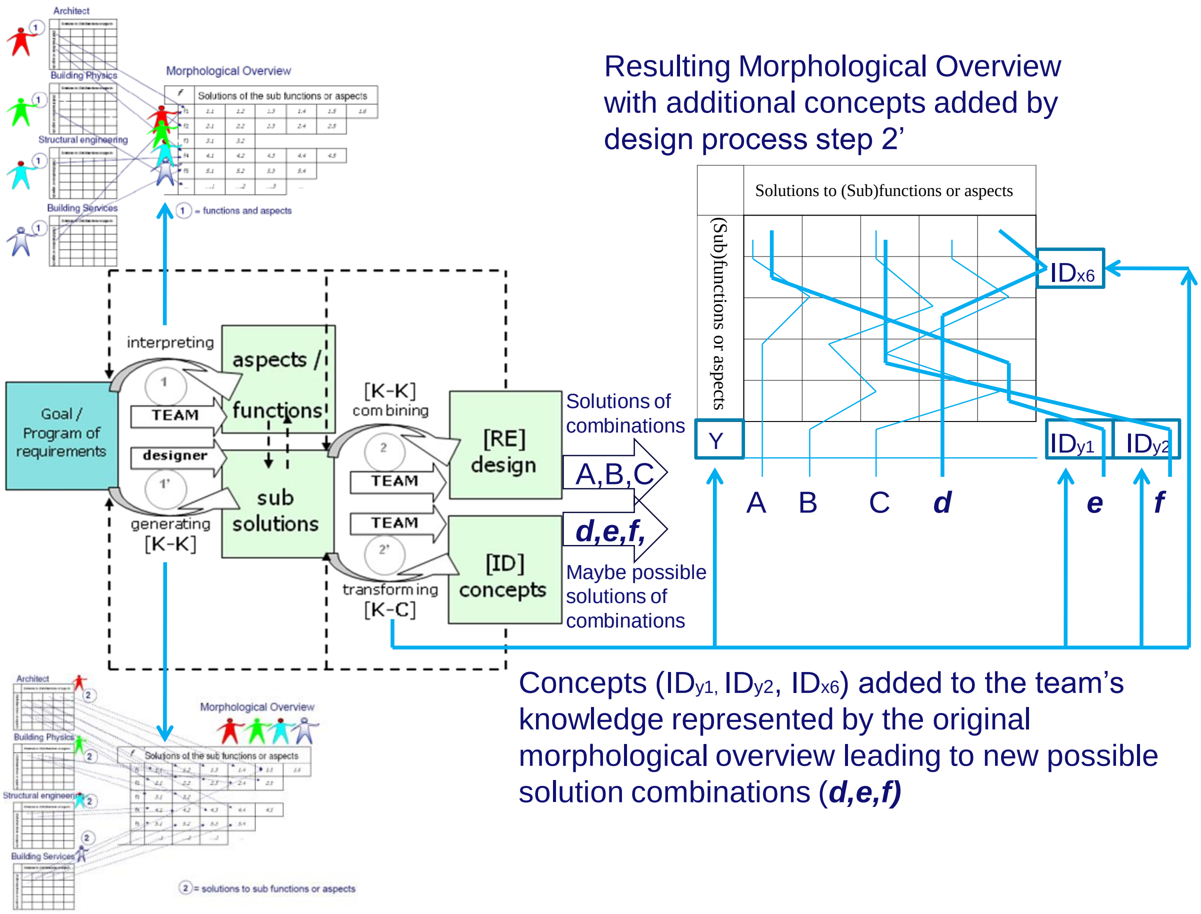


Figure 3: Integral Design model with C-K transformations, leading to solution of combinations [A,B,C] and leading to maybe possible solution concept combinations [***d,e,f***]

Within the ID approach, after the first step of generating discipline specific morphological charts and discussing the results as a team, the individual charts and 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 it into a proposed design solution. This step can take two forms:

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

The ID-model wishes to force the focus on the distinction between redesign [K-K] and concept generation [K-C]. The elements ID_{x6}, ID_{y1} and ID_{y2} represent conceptual sub solutions as a result of the concept generation K-C, see Fig. 3. This distinction is crucial since, we firmly believe, that the development of new concepts is essential if we would like to generate creative sustainable solutions to the highly complex contemporary design problems that our societies face. In this research the main area of interest lies in the conceptual phase of the design process. In essence, in the current research ID-concepts are seen as essential for the creation of new, innovative building designs, which increase the possibility to ultimately realise sustainable building solutions. Perhaps more importantly, ID-concepts represent the potential for the definition of new object design knowledge, which can then be exploited to solve future design problems.

Experiments: Workshops for professionals

To test our approach of the morphological overviews and to determine if the approach led to positive effects for the professionals, we arranged workshops as part of a training program for professional architects and consulting engineers [structural engineers, building services engineers and building physics engineers]. 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. These design exercises were derived from real practice projects and as such were as close to professional practice as possible. Using workshops in which experienced professionals participated, a workable method was arrived at through iterative improvement of four key elements: design team, design model, design tool and design setting. The iterative development of the method results from housing the research within the Design Research Methodology framework [Blessing and Chakrabarti 2009]. In the current configuration [Fig. 4] stepwise changes to the traditional building design process type, in which the architect starts the process and the other designers join in later in the process, are introduced in the set up of the design sessions. 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: first all disciplines start working simultaneously within a design team setting from the very beginning of the conceptual design phase and secondly 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 so to correctly study in the fourth setting this process intervention of introducing 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.

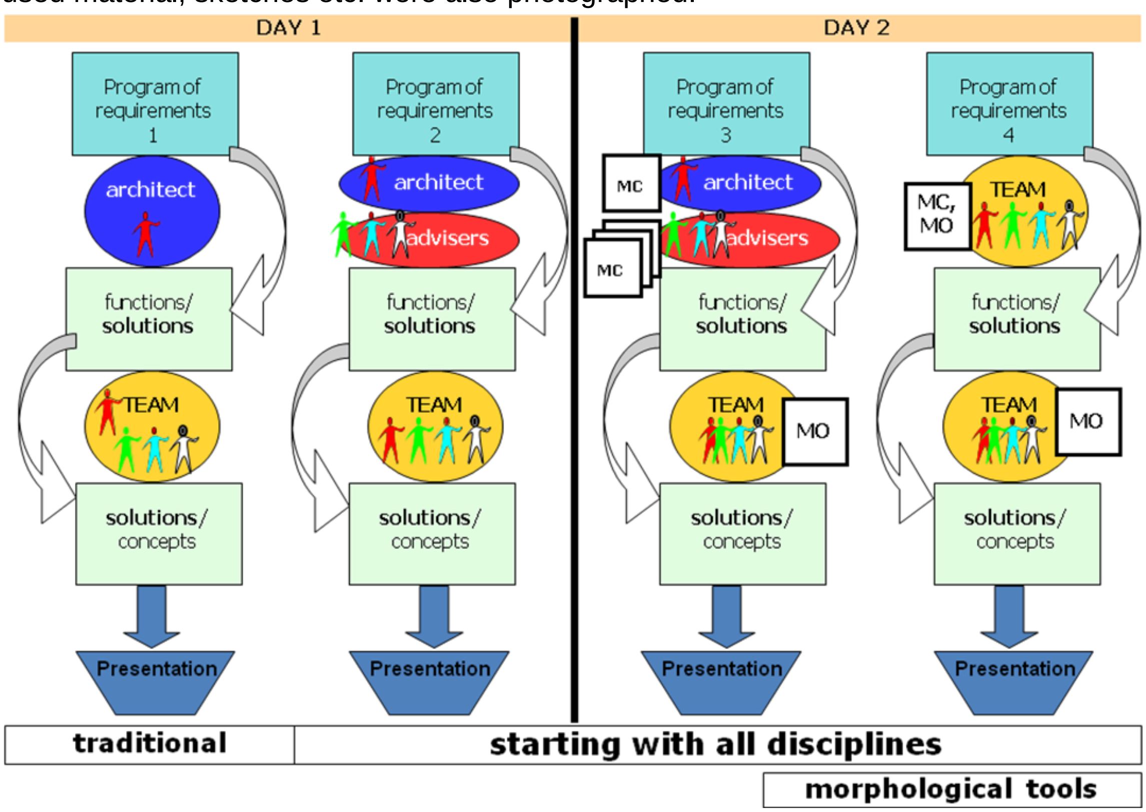


Figure 4: Workshops series 4 & 5, four different design set ups of participants and with or without Morphologic Overviews [MO] during the four design sessions within two days

Analysis I

The first goal of our research is to integrate engineering disciplines into a team design process and to share their knowledge at the outset of the conceptual design process. Therefore is it necessary to observe the actions by the participants during the conceptual design tasks. By this point in the research various observation methods and tools had been used Savanovic 2009]. Essentially, what was needed was a categorisation based only on functions/design aspects and solutions. Indeed, these are the things that participants needed to make explicit during the workshops. The idea appealed that the proposed design tool to structure these elements might just as well be used as a research tool to categorize them. Another advantage of using this tool is that it removes the need for live observation, which in early workshop set-ups had received consistently negative feedback from the participants and had also not yielded desirable results. For the sake of clarity, the tool in question is a morphological overview.

Here only a brief selection of all the results is given. The focus here is on the comparison of setting 1 session 2 [traditional building design setting] with that of setting 2 session 2 [where all disciplines work with the same information] and setting 4 [integral design setting with support of the morphological overview as design tool]. As an example only the process steps of one design team [group 1] is presented, as the process went similar for the other groups.

The compilation of the design team was such that only the architect was part of group 1 in all settings, the other members changed each time. More information and results are presented in Savanovic [2009].

Overall Workshop configuration of the workshops held in February 2008, is presented in table 1.

Duration	two days
Design sessions	4
Duration design sessions	2x2x120min [total 480 minutes]
Design task	Day 1 ‘parasite’ & ‘office’; Day 2 ‘renovation’ & ‘school’
Number of participants	19 in total, [day 1 – 18, day 2 – 16] 14 same for all four tasks
Architects	5
Building physics con.	4
Building services con.	7
Structural engineers	3
Observations by	Questionnaires, Photographs, Videos, all produced material collected

Table 1: Final two-day BNA-ONRI workshop

1st design setting, ‘parasite’ design task

Design session I: only architects, working individually - 5 architects

Design session II: team setting - 5 design teams

In design setting 1 each team was given the same design task: to design a ‘parasite’ structure to be placed on the building that the workshop was taking place in. For full description of the design task see Savanovic [2009]. All teams proceeded with the task in the same way. Initially, in the first design session, which lasted approximately 30 minutes, the architect worked alone on the design. Basically, this was done to mirror the status quo in which the architect is responsible for the original design, which is then presented to engineering disciplines. Following this, the other engineering disciplines of the design team joined the architect in order to discuss the proposed design. In this sense, the design team members of the engineering disciplines adopted the reactive role that is the norm in the status quo, and gave their reactions to different aspect of the design proposal. On the basis of these reactions the architect made adjustments to his original design. These adjustments led to improvements of the design.

In order to demonstrate what occurred in design setting 1, the work and analysis of one team is presented below, while the work of the other four teams can be found in Savanovic [2009]. After the initial design session I, in which the architect worked alone, all team members met in design session

II, to discuss the design. Here, the architect led the discussion. He did so by first explaining the considerations he took into account while working on his design. Through analysis of the session, these considerations were recorded in the Table 2 below. The analysis of each team's work started with the translation of the architect's explanation of the initial proposal at the beginning of second design session is into a table of aspects and sub solutions. This resulting sequential list is then structured in the architect's morphological chart. Then, on the basis of a review of the videotaped session,a table of aspects and sub solutions considered by the design team is structured in the design team's morphological overview. Design team 1 consisted of: architect [A], building physics consultant [BP], building services consultant [BS], and structural engineer [SE] [4 members from 4 disciplines].

Time (design session II)	Who	Aspect or sub solution	Description	Text/sketch or verbally
00h04min	A	Aspect (1)	Form	Text (session I)
00h04min	A	Aspect (2)	Materialisation	Text (session I)
00h04min	A	Sub solution (1-1, 2-1)	Contrasting to the existing building	Text (session I)
00h04min	A	Sub solution (2-2, 3-1)	Wood	Text (session I)
00h05min	A	Sub solution (2-3)	Open structure	Text (session I)
00h05min	A	Aspect (3)	Sustainability	Text (session I)
00h05min	A	Sub solution (4-1)	On (the existing building)	Text (session I)
00h05min	A	Sub solution (4-2)	Against (the existing building)	Text (session I)
00h05min	A	Sub solution (4-3)	Loose (from to the existing building)	Text (session I)
00h06min	A	Sub solution (4-4)	In the middle (of existing building)	Text (session I)
00h06min	A	Solution!	'Roof' on the existing roof…	Sketch (session I)
00h09min	A	Solution!	Loose, vertical spiral addition…	Sketch (session I)

Table 2: Aspects and [sub] solutions as explained by architect 1 to design team 1 [session II]

In order to allow comparison between different design teams and settings, these tables were reconfigured into the form of morphological overviews. The analytically derived morphological overview of team 1 is presented in Fig. 5. The aspects/functions and sub solutions originally brought to the table by the architect can be found as {A} in Fig. 6. After the discussion with the designer of other disciplines the team decided to work on different functions leading to the morphological overview of Fig. 6, which represents the final result of the design session.

Design aspects/ functions:	**Sub solutions:**			
(1) Form {A}	(1-1) Contrasting {A}			
(2) Materialisation {A}	(2-1) Contrasting {A}	(2-2) Wood {A}	(2-3) Open structure {A}	
(3) Sustainability {A}	(3-1) Wood {A}			
(4) [positioning]	(4-1) On {A}	(4-2) Against {A}	(4-3) Loose {A}	(4-4) In the middle {A}

Figure 5: Architect's morphological chart

Design aspects/ functions:	**Sub solutions:**			
(3) Sustainability{A}	(3-1) Wood {A}	(3-2) Heat pump {BP}	(3-3) Natural ventilation {BP}	
(4-1) On [positioning]	(4-1-1) 90° over the ex. building, on own legs {BP}	(4-1-2) 35-meter beams {SE}	(4-1-3) In line and partly over the ex. Building {BP}	(4-1-4) V-shaped columns {A/SE}
(5) Demountable {SE}	(5-1) flexible, prefab system {SE}	(5-2) plug'n'play building services {Team}		
(6) [Entrance]	(6-1) Independent {A}	(6-2) Extend existing entrance {A}		
(7) Flexibility {BS}	(7-1) Theatre at the end {A}	(7-2) entrance on west side {BP}		
(8) Orientation, sun {BP}	(8-1) roof wider than floor {A}			

Figure 6: Design team's morphological overview

2nd design setting, 'zero energy office' design task

Design session I all disciplines separately:
5 architects
3 building physics consultants
7 building services consultants
3 structural engineers
Design session II team setting: 5 design teams.

The analysis of the second design sessions of the second workshop design setting is based on videotaped design team activities. The resulting table of aspects and sub solutions considered by design teams during session II is structured into the design team's morphological overview. The goal of setting two was to make minimal changes to the status quo and measure the effect on the design process and the final product. To reach this goal at the beginning of the design process in design session 1 all disciplines were asked to respond to the design brief, as opposed to only the architect in the previous setting. In practice the participants worked together with members of the other teams from the same discipline. In effect, this led to the creation of four mono-disciplinary teams. All of these teams ended up with one finished product. The individual disciplines took this product back to the multidisciplinary team. These discipline-based responses were then brought to a team discussion in design session two. How much of this product was used in the multidisciplinary team and in what way was down to the representative of each discipline. The logic for following this procedure was to see if asking all disciplines to work on the task from the outset had any effect on the amount of aspects/functions and sub solutions that were generated by design teams during design session II. The analysis of the team work of design team 1 in design session II is shown in Fig. 7. Design team 1 consisted of: A, BP and BS: 3 members from 3 disciplines.

Design aspects/ functions:	**Sub solutions:**			
(1) Keep sun out {A}	(1-1) Trees {BP}	(1-2) Overhangs with PV panel{BS}	(1-3) reflective glazing{BP}	
(2) Light {BP}	(2-1) High-frequency lighting {BP}	(2-2) Solar tubes {A}		
(3) Heating {BS}	(3-1) office to storehouse {BP}	(3-2) TES {BP}	(3-3) sedum roof {BS}	
(4) [cooling]	(4-1) Adiabatic cooling {BS}	(4-2) Night ventilation {BS}	(4-3) air intake underground {A}	(4-4) In the middle {A}
(5)Electricity {A}	(5-1) Wind turbin{BS}			

Figure 7: Design team 1 morphological chart

In order to determine the effect of the set-up of setting two it must be compared to setting one. The main point of interest is to assess whether requiring individual disciplines to consider the task from the outset had any effect on the number of sub solutions generated when the individuals came together as a multi-disciplinary team. The comparison is presented below: table 3 contains the aspects and sub solutions generated by each individual team in setting I; table 4 contains the aspects and sub solutions from each individual team in setting II.

	Team 1	Team 2	Team 3	Team 4	Team 5	Average
No. of aspects	5	7	2	5	7	5.2
No. of sub solutions	13	16	12	16	17	14.8

Table 3: Aspects addressed and [sub] solutions produced by design teams [setting I]

	Team 1	Team 2	Team 3	Team 4	Team 5	Average
No. of aspects	5	2	3	3	3	3.2
No. of sub solutions	13	5	7	8	7	8.0

Table 4: Aspects addressed and [sub] solutions produced by design teams [setting II]

As can be seen from the table, contrary to what one might have expected, the intervention of introducing other disciplines into the design process from the outset did not result in the generation of a greater number of aspects and sub solutions. On the contrary, in setting two fewer aspects and sub solutions were generated than in setting 1, which was meant to represent the status quo.

3th design setting, 'renovation' design task
Team setting for both design sessions: 5 design teams.

Design setting 3 represented a learning-by-doing opportunity for the individual disciplines and the design teams. The ideal outcome would be that each team could clearly demonstrate successful use of the design tools during the design process. However, as a key part of learning is feedback, after the teams completed tasks set in setting 3, time was given to compare and appraise the teams' work and to answer any questions that arose. The results of this learning session are discussed in Savanovic [2009] but are not relevant in the context of this article.

4th design setting, 'school' design task
Team setting for both design sessions: 5 design teams

Design setting 4 represents the very last stage in the cycle of research in this research project. All of the individual interventions that were used in the earlier research stages are combined so that in setting 4 the ID-method can be tested. To be explicit, the elements that have been combined are: design team, design model, design tool and design setting. The analysis of the fourth workshop design setting, in which 5 design teams participated, of team 1 is here presented. Design team 1 consisted of: A, BS, SE: 3 members from 3 disciplines. In this setting, all of the design teams' proposed sub solutions were recorded directly on morphological overviews, see Fig. 8.

Design aspects/ functions:	Sub solutions:					
(1) Sustainability {Team}	(1-1) 'green' façade {A}	(1-2) PV/T shadings {BS}	(1-3) 'buffering' for humidity {A}	(1-4) roof garden {BS/A}		
(2) child-friendly, healthy {Team}	(2-1) Scale, identity {A}	(2-2) natural materials {BS/A}	(2-3) structure, protection {A}	(2-4) open façade, windows {A}		
(3) Natural ventilation {Team}	(3-1) HOLCOM ventilation {BS}	(3-2) higher classrooms {BS}	(3-3) walls for ventilation {BS}	(3-4) building orientation {BS}		
(4) Energy sustainability {Team}	(4-1) photo-voltaic thermal	(4-2) adiabatic cooling {Brief}	(4-3) air-inlet via underground {BS}	(4-4) CHP for winter {BS}	(4-5) floor heating {A/BS}	(4-6) sprinkler comb. cooling {A}
(5) Flexibility {Team}	(5-1) Columns {SE}	(5-2) Walls {SE}	(5-3) C/W Combination {Team}	(5-4) System plafond {A}	(5-5) 'Clear' plafond {A}	(5-6) HOLCOM floor {A}

Figure 8: Design team 1 morphological overview [design setting 4]

To conclude this section comparison is made between settings 1 and 4, and the research questions that were stated for setting 4 are answered. Table 5 contains information on the number of aspects and sub solutions generated by the teams in the setting four.

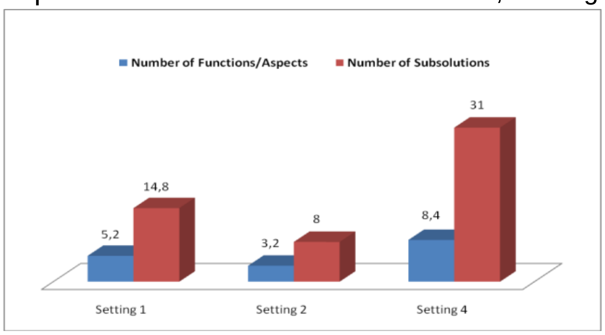
	Team 1	Team 2	Team 3	Team 4	Team 5	Average
No. of aspects	5	11	11	5	10	8.4
No. of sub solutions	24	26	39	20	46	31.0

Table 5: Aspects addressed and [sub] solutions produced by design teams [setting IV]

Result I: The use of the design tools and the team approach confirmed that goal was was realised

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.

From the analysis of the workshops it could be concluded that the solution space, resulting from the number of functions and aspects considered, was significantly increased by applying the Morphological Overviews. A good example of this increase can be seen from the results from session 1 [without morphological charts and morphological overview] compared with the results of session 4 [with use of morphological charts and morphological overview]. Figure 9 clearly show that, as expected, more aspects and sub solutions were generated in setting 4 than in any previous setting 1 and 2. The increase of the number of considered functions and aspects leads to a larger number of partial solutions, which implies an increased problem-solution space, defined as the number of aspects times the number of solutions, see Fig. 9.



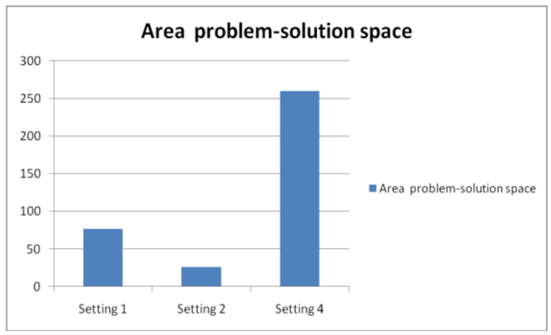


Figure 9: Comparison of the number of aspects/functions and the number of partial solutions being generated by the design teams in design session 1 & 4 and as an overall indication the 'problem-solution' area

Result II: Transformation of initial design knowledge to concepts

The results of analyzing the transformation of initial design knowledge into design concepts with the help of morphological charts and morphological overview showed that the Integral Design method did prove successful in facilitating the inclusion of engineering knowledge from the outset of the conceptual design phase. 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. However, what the disciplines within design teams ended up doing in many instances amounted to no more than seeking to fit solutions to design tasks. In essence, the design teams' approaches could best be categorised as 'integrated' rather than the desired 'integral' design, leading to redesigns [RE] rather than the desired integral design concepts [IDC]. This research therefore cannot claim to have realised the aim of using the ID-method to arrive at integral design concepts.

Conclusions and further research

The ID(Integral Design)-model is relevant to demonstrate the need for the explication of individual disciplines' object-design-knowledge. Additionally, the model can focus design teams on this object-knowledge in order to encourage the creation of ID-concepts. Although object-design representations can be driven by individual interpretations of the design task, in order to arrive at integral design concepts it is necessary that at a certain point the team agrees on design aspects / functions.

The main characteristic of the ID-method is the use of design teams' object-design-knowledge as 'building blocks' for either redesign [RE] or integral design concepts [ID]. The clear distinction between the two, redesign and design concepts, is only possible by using C-K theory. Building object-design-knowledge is discipline based, and to get an overview of the knowledge needed to produce a sustainable building concept in a specific context implies a team design approach as the first prerequisite. Research has shown that a highly promising way to get different disciplines truly working together is in a face-to-face setting [Abadi 2005, Emmitt and Gorse 2007]. Our experiences through the workshops and the feedback from the participants confirmed this. In addition, creating a workshop environment allowed professionals to work openly and freely, without the burdens that a laboratory setting bring with it.

The results showed that the ID-method did prove successful in facilitating the inclusion of engineering knowledge from the outset of the conceptual design phase. 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. However, what the disciplines within design teams ended up doing in many instances amounted to no more than seeking to fit solutions to design tasks. In essence, the design teams' approaches could best be categorised as 'integrated' rather than the desired 'integral' design. This research therefore cannot claim to have realised the aim of using the ID-method to arrive at integral design concepts. Nonetheless, the ID-method represents a set of necessary conditions for the creation of integral design concepts. More importantly, reflected by the expressed satisfaction of the majority of the participants, the ID-method represents an important step in what is argued as a necessary change in current building design practice.

In the next stage of the research the use of so called C-constructs will be investigated to stimulate the creation of new concepts. These C-constructs, sometimes called C-projectors, are used by Hatchuel and Weil in their KCP [Knowledge-Concepts-Proposition] workshops [Hatchuel et al 2009] to stimulate the forcing of concepts. The KCP workshops were held in different companies in France and more recently in Volvo in Sweden [Elmquist en Segrestin 2008, 2009]. The use of C-constructs could lead to increased effectivness of the Integral design workshop, and especially to an increase of the solution space by stimulation the transformations of K-C and C-K. In this research morphological analysis combined with the C-K [Concept-Knowledge] theory was used to explain the different design steps that take place in the conceptual design phase. Further research will start with a different approach for the analysis of the two final workshops series. A literature study will be done to determine analysis methods for conceptual design sessions: especially methods from linguistics and argumentation theory [Stumpf and McDonnell 2002, Dong 2007, Dong 2009]. Based on this analysis a new support tool will be developed and tested in new workshops series.

Acknowledgements

The project is financial supported by the foundation 'Stichting Promotie Installatietechniek (PIT)'.

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