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Integral design: the new roles for architect and engineers for developing nearly Zero Energy Buildings

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Abstract: Improving the built environment is a cornerstone for sustainable development ultimately leading to Zero Energy Buildings. There is the urgent need for innovation. The urgent need for innovative and sustainable built environment has led to a more complex design process. As a result, the architect requires increasing support from specialized engineers in multi-disciplinary design teams. A design method was developed, based on the use of morphological charts and a morphological overview, to support design teams with structuring and organizing their communication and knowledge. After testing the method in workshops in industry, it was applied at the department of architecture for master students for their multidisciplinary master project, integral design of a nearly Zero Energy Building. Our experiments showed that it is possible to stimulate the innovative outcome of multidisciplinary design teams within the conceptual building design phase by changing their traditional roles into new team’s roles.

Keywords: Innovation, sustainable development, integrated building design, workshops, conceptual design

Biographical Notes: Wim Zeiler is a professor in Building Services at the University of Technology Eindhoven. His research is focused on integration of renewable energy within the built environment, intelligent buildings and smart grids.

1 Introduction

Sustainability is a crucial issue for our future and architecture has an important role to direct sustainable development (Taleghani et al 2010).
Buildings are central to the EU's energy efficiency policy, as they are responsible for nearly 40% of final energy consumption and 36% of greenhouse gas emissions (Eurostat 2013, Grözinger et al. 2014). In response to climate change and the ‘peak oil’ phenomena, architecture should encompass the environmental task of designing a low carbon built environment (Chen et al. 2011). The general public became aware of the problems related to this energy consumption and sustainability as Al Gore sounded the alarm bells with his ‘inconvenient truth’ World tour. However, the concept of sustainability is not something new. In 1987 the United Nations (UN) commission defined sustainability as; “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland 1987). Attempts were made to develop international consensus on sustainable building design in ISO 15392 entitled ‘Sustainability in building construction – General principles’, which confirms the understanding of sustainability suggested in the Brundtland report, but aside from this does not provide building designers with all of the necessary valuable design principles (Hansen and Knudstrup 2009). Still, sustainability has become a cornerstone for many organizations. Clients have become especially sensitised to the value aspects of design to the point where project briefs are handed out with specific building performance-targets that needs to be met (Holzer 2009). Sustainable development was brought into mainstream conservation on a global scale through sustainable assessment tools like LEED (Leadership in Energy Efficient Design) and BREEAM (Building Research Establishment Environmental Assessment method) applied in building design (Rivera 2009). For the assessment of sustainable projects practitioners currently rely on certification schemes such as BREEAM and LEED (Hansen and Knudstrup 2009). Although these certification methods primarily focus on energy and environmental sustainability, they also include social and economic sustainability issues. However, they do not facilitate proactive investigation of the creative solution space of a project or the aesthetics involved in building design (Hansen and Knudstrup 2009). Building design needs to provide economically and architecturally acceptable solutions for sustainability issues ranging from flexible use to renewable energy, energy reduction measures while maintaining and even increasing comfort levels 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). This led to the development of nearly Zero Energy Buildings (nZEB): a building which uses during a year’s overall energy balance nearly no
energy. However this new target in building design, requires totally
different approach from conventional building in terms of design,
construction and operation (Ritter 2010, Kang et al. 2010). As a result
there is a continuous path towards higher performance buildings (Erhorn
and Erhorn-Kluttig 2012). This path is not completely clear as indicated
by the discussion about nearly Zero, net Zero and Plus Energy Buildings
(Voss et al. 2012). The ultimate goal is to design and build buildings that
give more than they take. (Active House 2013,Gyling et al. 2011). The
construction industry is in the early stage of a revolution to reinvent the
design process that was used before the large scale application of HVAC
systems (Heiselberg 2007). The traditional design process was usually a
fragmented process where engineers and other experts are introduced after
some of the most influential design decisions have already been made
(Heiselberg 2007) which in many cases leads to non-optimized buildings
by non-integrated addition of sustainable options like renewable energy
systems or energy efficiency measures (Löhnert et al. 2003, Poel 2005,
Brunsgaard et al 2014). The goal here is to develop an integral design
approach that can eventually lead to the required conditions for innovation
of the end product; the sustainable building (Seppänen et al 2007). No
longer are buildings designed by architect’s alone, a whole design team,
with members from different disciplines, is required to cope with the
complexity of the current necessary sustainable development. During
building design processes, synergy between the different disciplines
involved in the design process is necessary to reach good sustainable
building designs. Although the main focus within nZEB design is often
energy related, there are more important sustainable aspects such as
economic, social and environmental conform ISO 15392-2008 (Hansen
and Knudstrup 2009).

King (2012) stated that in order to do anything meaningful in terms of
moving to low carbon society, we need a consistent framework and design
method, within which we can apply knowledge embodied in a design
team. The main body of the paper starts (Section 2) with the development
of an integral design method: a design method that helps to merge the
different perspective of all designers and engineers involved in the design
process. The testing of this method in practice was achieved through
design workshops for professionals, architects and engineers in the
building domain. This is described in section 3. This workshop model was
used as reference for other experiments with students instead of
professionals. In the experiments with students, an intervention to the
process was made by introducing a professional to the students teams. In
section 4 the results are presented of the application of the integral design
method within the workshops. A discussion about using the developed integral design method to support building design teams to generate solutions for the highly complex problem of designing extreme sustainable buildings (nearly zero energy buildings) is given in section 5. Finally, in section 6 some conclusions are given about the added value of the presented approach for the generation of solutions for a low carbon built environment. As stated by Janet Beckett, director at Carbon Saver a consultant company specialised in Low Carbon Building design and building engineering physics, there could not be a better time than now in time of global change to implement a paradigm shift – we cannot continue in the same vein (Beckett 2012). Earlier dialogue and true cooperation in the project design means it is easier to build on sustainability, and add innovation and engineer integrated solutions (Beckett 2012). A new kind of architect is needed, who can accept the principles of engineering alongside the building aesthetics. A new generation of architects to be inspired by engineering and science, according to Beckett (2012), willing to listen to concepts and ideas that can be both beautiful and useful as well as sustainable. Also a new kind of engineer is needed, one who is better able to communicate about possible alternative proposals as well as the realities of how engineering services impact on the building and not just solving problems or making calculations.

This article is a revised and expanded version entitled ‘Integral Design: the new roles for architect and engineers for sustainable development’ presented at Engineering Education for Sustainable Development 2013, Cambridge September 23-25. Especially the comparison between the results between professionals and students is extended with more results and details. It proves that integral design supports architects and engineers the new roles for architect and engineers for developing nearly Zero Energy Buildings

2 Methodology: Integral Design

2.1 The need for another design approach
Sustainability is a crucial issue for our future and architecture has an important role to direct sustainable development (Taleghani et al 2010). However new approaches are needed to bridge the gap between ‘Art (Design)’ and ‘Science (Engineering)’ worlds, in case of the building design specifically between architects and consulting engineers (structural, building physics and building services). Education has a vital role to play in developing sustainable development.
The key concept of “Integrative design” or sometimes called “whole system design.” is that optimizing each component of a system independently leads to non-optimal complete systems, especially when energy efficiency sustainability becomes a goal. Integrative design requires a multi-disciplinary team. At this point it is good to define the differences between integrative design and integral design more explicitly. Within integrative design the perspectives of two or more disciplines are combined in order to become more effective, within integral design all disciplines necessary and important are treated as part of, or contained within the whole building design approach. To put it in another way, within integrative design the architectural discipline and other disciplines start separately and often in different design phases and are later made to fit. Whereas, within integral design all necessary design disciplines start together right from the conceptual design. In order to achieve not only integration, but true synergy between all disciplines a single designer has to ‘force’ himself or herself to consider different disciplines based viewpoints while designing. Even if a designer has the ability to deploy most of these viewpoints, he or she usually does not have enough specialist knowledge to assess all of them in depth. For this reason, it is assumed that a multi-discipline design team’s view on design is a better way of pursuing building design synergy than a mono-disciplinary individual designer’s view on design. Furthermore, as design within the built environment is becoming more complex the information and knowledge exchange between participants within building design process is increasing. As a consequence, the coordination between the different disciplines involved is also becoming more difficult; a new approach in designing thus is required in order to reach synergy.

In contemporary building design the roles of architects and traditional discipline based consulting engineers are changing. Engineering consultants now have to do more than was traditionally expected from their engineering discipline, as stated by one of the major Dutch building consultants firms (DGMR 2011). By combining domain specific knowledge, like structural and building-services related solutions, they are now capable of making significant improvements in the areas of sustainability and energy consumption. Ideally, in the capacity of engineering consultants, they should draw up the pre-conditions to which the architect must adhere in their designs (DGMR 2011). The solution for improving the overall quality of building design might be found within the design team itself and letting the design team functioning as a real team. This implies equality and mutual respect between the various disciplines within the design team. However, this is not something easily achieved
and design tools and methods might help the process. Adequate design tools and working methods are needed which could help architects in the design process (Kanters et al 2014). The Architecture, Engineering, Construction (AEC) industry is a knowledge intensive industry which has to create sustained organizational and societal values (Rezgui et al. 2010). The increased complexity of building design inevitably calls for more design collaboration (Lee and Jeong 2012). In the projects designed (and built) in the early 2000s, architects started to adapt their usual design process (traditional design process) by consulting engineers in an earlier stage than normally done. In sustainable building projects designed later, many architects qualified their design process as an Integrated Design Process (IDP): the architects mentioned the early engagement of engineers in the process as a clear sign of this (Kanters et al 2014). As nearly all the important decisions have to be made at this time, it is important that all design disciplines start together in the conceptual design phase (den Hartog 2003). Traditionally this is not the case and some disciplines get involved later in the design process, which leads to the influence/information contradiction. At the beginning of the design all important decisions has to be made based on still incomplete information, see Fig. 1.

As complexity of the design increases with the efforts to reach the limit of zero impact, it really becomes necessary to involve all building design disciplines in the earlier stage of such design project. This early collaboration with engineers was found to be crucial in order to develop and implement sustainable architecture. However, this collaboration in the early design phase was not always easy for the architects: engineers ‘spoke another language’, were often ‘too specialised’, and ‘not willing to compromise on certain issues’ (Kanters 2014). This is not something done by merely putting the different designers together around one table, but needs more support. So, the building design process has become more heterogeneous, with several diverse actors involved such as architects, engineers, contractors and clients. In effect, in order for the contemporary architect to provide a cutting edge concept for a zero energy building, he must view the engineering disciplines as de facto co-designers and as such vest them with integral roles within the design team towards early design phases especially conceptual design, see Fig. 2.

Viewing engineers as co-designers has a number of consequences worthy of note. First, the relevant engineering knowledge to work towards zero energy buildings is dispersed throughout a number of engineering sub-disciplines, which implies the need for a variety of engineering disciplines
to be included in the design team, e.g. structural engineers, HVAC engineers, Building Physics engineers etc. Second, to gain the maximum value from this engineering knowledge and to make the design process as efficient as possible, the engineering disciplines must be included in the earliest possible stage of the design process, which can be understood as the conceptual design stage. Third, both the architect and the engineering disciplines will have to learn new skills in order to function productively in a design team scenario. The engineers will have to operate less as traditional calculating engineers, and more as designers who contribute to a shared team concept. Conversely, the architect will have to learn to be much more inclusive in the design process and allow the engineering disciplines to actively contribute to the dynamic design process rather than rely on engineers to simply verify or optimise his own design contributions. Finally, in order to facilitate the inclusion of engineering knowledge into the design team, it is necessary to provide the design team with simple and intuitive methods and design tools that the engineering disciplines are comfortable using.

2.2 Integral Design
In building design one has to work with ill-defined problems where the solution and the problem itself develop almost in parallel at the early stages of the design process. Also, the amount of relationships and dynamic social interactions makes design increasingly complex. Therefore, a method is needed to structure would be design solutions for wicked design problems (Simon 1969). Due to problems with the lack of quality of products and projects, in the early 1960s researchers and practitioners began to investigate new design methods as a way to improve the outcome of design processes. Since then, there has been a period of expansion through the 1990s right up to the present day (Cross 2007, Chai and Xiao 2012, Le Masson et al. 2012). However, there is still no clear picture of the essence of the design process (Horváth 2004, Bayazit 2004; Almefelt 2005 a,b) and many models of designing exist (Wynn & Clarkson 2005, Pahl et al. 2006, Howard et al 2008, Tomiyama et al. 2009, Ranjan et al 2012, Gericke and Blessing 2012).

After studying different design methods it was decided to try to use a method derived from the General System theory: methodical design (Zeiler and Savanovic 2009). In the Netherlands methodical design is a quite familiar design method in the domain of mechanical engineering and being taught at different educational institutes. The methodical design process is an in principle application-independent method with its connection to the general system theory and has some exceptional characteristics (Blessing 1994): it is problem oriented and distinguishes
based on functional hierarchy various abstractions or complexity levels during different design phase activities. The design phases of the methodical design were extended by us into the integral design method which consists of the cycle [define/analyze, generate/synthesize, evaluate/select, implement/shape] representing the sequence of design activities that take place, see Fig. 3.

This design method was further extended by us through the intensified use of morphological charts developed by Zwicky (1948) to support design activities in the design process (Zeiler and Savanovic 2009, Savanovic 2009) and the specific use of a morphological overview built from the morphological chart.

The morphological charts are formed as each designer translates the main goals of the design task, derived from the program of demands, into functions and aspects. These functions and aspects are then listed on the first vertical column of the morphological chart, see Fig. 4. After this first step, in the second step the (with the mentioned functions and aspects related) proposals can be listed on the corresponding rows. Each participant of a design team develops a Morphological Chart from their own specialist perspective to the design brief.

The use of the 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, Ritchey 2010). The morphological chart (MC) to visualize sub-solution alternatives play a central role in the integral design approach for design teams. The morphological overview of an integral design team process is thus generated by combining in two steps the different morphological charts made by each discipline. First, functions and aspects are discussed and then the team decides which functions and aspects will be placed in the morphological overview. Then, after this first step, all participants of the design team can contribute their solutions for these functions and aspects by filling in the rows within the morphological overview. Putting the morphological charts together enables ‘the individual perspectives from each discipline to be put on the table’, which in turn highlights the implications of design choices for each discipline. This approach supports and stimulates the discussion on and the selection of functions and aspects of importance for the specific design task, see Fig. 5.
In case of building design, morphological charts can be used to explicate discipline-based object design knowledge. Merging morphological charts of all involved disciplines results in morphological overview of the available object-design-knowledge within a design team. However, morphological overviews are not to be regarded as the end result of the team design process, rather as the initial phase based on which integral design can be done. Contrary to the example from Almefelt’s approach in the context of a Swedish car company, morphological overviews need to be incorporated into the ID-method as primarily a design and not decision making tool.

The description of the morphological overview may read as minor implementation difference of the old morphological matrices. However based on the applied Integral Design method to structure the design process and using its design tools, the effect of using the morphological overview can be presented in analogy with the model of Badke-Schaub et al (2007), see Fig. 6 (A) and (B) (Zeiler 2014).

Based on the given design task, each design team member perceives reality due to his/her active perception, memory, knowledge and needs. The morphological charts represent the individual interpretation of reality, leading to active perception, stimulation of memory, activation of knowledge and defining of needs, see Fig. 6. Within the morphological overview this individual results can be combined with those of the whole design team. As such the morphologic overview can be used to illustrate how the mental model in design teams develop. The morphological charts and morphological overview of the Integral Design method can be used to make parts of the team’s mental model transparent. The individual morphological charts of each individual designer represent their active perception, their activate part of their memory, their individual knowledge as well as their interpretation of the design needs. The morphological overview is than the representation of the design team’s interpretation/perception and activated memory/knowledge: the design team’s mental model.

As the Integral Design start from the program of requirements the method especially emphasizes the sustainable development necessary to achieve nZEB especially when designers and engineers do not have a sustainable perspective. Due to reflection within the design team during the process, sustainable thinking is developed and thus it becomes more than just merely creation of mapping disparate skill sets within the team. The multidisciplinary dialogues leads to knowledge sharing (the morphological charts), knowledge integration (the morphological
overview) and knowledge generation (new solutions which were not included in the morphological charts, but are inspired by them). During this process the information from the morphological charts are discussed and explained to each other. Any barriers to communication are overcome by the team members by solving the misunderstandings and development of a shared insight, which forms the basis for the morphological overview. This engenders a sense of unity within a design team while ensuring good communication, commitment and productive design sessions (Harries 2009).

3 Experiments

3.1 Workshops for professionals

Since 2000 together with the Dutch Royal society of architects (BNA), the Dutch Association of Consulting Engineers (ONRI), the Dutch Society of Building Services Engineers (TVVL) and different Roofer associations, workshops series were organized in which a total of more than two hundred professionals with at least 12 years’ experience voluntarily participated. After extensive experimenting with different workshops set up’s, it was determined that a 2-day workshop setting was sufficient (Savanovic 2009). These final 2-day workshop series was arranged as part of a training program for architects and consulting engineers (structural engineers, building services engineers and building physics engineers) (Savanovic 2009), as well as for architects and contractors (Quanjel 2013).

The designers had to work on different design tasks during the workshops. 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 were on the same level of complexity and were used in all workshops. In the workshops 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, were introduced in the set-up of the design sessions, see Fig. 7, more details can be found in (Savanovic 2009);

- Session 1 traditional design setting architect start and after a while the other designers/consultants join the process. Design task: a net zero energy pavilion on the building the workshop was taken place in.
- Session 2 all design team members start at the same moment together. Design task: a net zero energy office
- Session 3 all design team members start at the same moment together with the help of the design method using morphological charts and a
morphological overview. Design task: a net zero energy roof extension of an existing warehouse
- Session 4 is the same as session 3 only now the participants were given a thorough feedback about their use of the tools in session 3. Design task: a net zero energy school.

3.2 Workshops for students
To design energy-efficient architecture like nearly Zero Energy Buildings (nZEB), it is not just a matter of bringing all participants together or the use of tools. It is also about the approach to designing nZEB in itself that needs to be addressed and especially in education (Brunsgaard et al. 2014). In connection with the integral design research project for professionals in the Dutch building industry, we developed an educational project, the master project integral design. Development of knowledge and skills and the ability to apply them is the main task of the multidisciplinary masters’ project integral design. Interaction between practice, research and education forms the core of the integral design method. Also besides the experienced professionals the students allowed us to see the different effects of the proposed design method on a group with no working experience. Therefore the concept of the integral design workshop for professionals was implemented within the start-up workshop of our multidisciplinary masters’ project. The different design assignment all were related to the design of net zero energy buildings. These complex tasks require early collaboration of all design disciplines involved in the conceptual building design. The supportive design method of this project, which serves as a learning-by-doing start-up workshop for master students, is the integral design method with its use of morphological charts and the morphological overview. Each year there were 6 teams consisting of 4 disciplines: architecture, structure, building physics and building services. In total 74 students participated during 2011-2013.

The structure of the aforementioned workshop for professionals was applied in the educational “Multidisciplinary master design project”. The basis of this project was the use of the learning-by-doing workshop approach with its use of morphological overviews. The integral design workshops were the start-up workshop of our multidisciplinary masters’ project on University of Technology Eindhoven, Department of Architecture, Building and Planning. Students from architecture, building physics, building services, building technology and structural engineering were offered the opportunity to participate. During the first week the Professional workshop formula was used to start the design team work.
Students performed different design assignments which were based on the assignments tested in the workshops for professionals the Multidisciplinary master design project (Savanovic 2009). The intention was to see the effects of the design method and compare the results of the students with those of the professional workshops series of Savanovic (2009).

All the assignments of the different sessions were related to aspects of nZEB and had a similar level of complexity which made the results comparable. This made it possible to compare the results and design approaches of the students with those of the professionals (Zeiler 2011). The selection procedure was the same as for the Professional workshops; the only criterion for participation was being member of the ‘master students group’. The students were assigned to design teams of different disciplines to have all disciplines, architecture, building services, building physics and construction, represented in each team. The whole project took 14 weeks.

The original settings of the professional workshop was reduced to three sessions for the student’s workshops, which proved to be quite as effective (Zeiler 2011). The student’s workshops started with an afternoon setting consisting of two sessions followed the next morning by a third session. The focus of the first day of the workshops was to teach the students the use of morphological charts and morphological overview. This was done by starting with a lecture about the integral design method and its specific application of morphological charts and morphological overviews as design tools. Also they got feedback on their morphological charts and their morphological overview. The students were divided in design teams that worked only once with the same students during sessions 1, 2 and 3. This was done to avoid a learning effect in teams as they otherwise start to know each other better after working together during a session. In sessions 1, 2 and 3 the participants worked individual on different design task and made their own morphological chart. After this the design teams made their morphological overviews.

4 Results

4.1 Professional workshops as reference

Here, only a brief selection of all the results of the professional workshops is given. More results and information were presented by Savanovic (2009). The overall quantitative results of sessions 1, 2 and 4 as well as the
difference between the different settings can be seen, see Fig. 8. Sessions 3 was a learning session to get used to the design approach, in which the designers had to apply morphological charts (MC) and create a morphological overview (MO). In this case it is not clear if you measure the effect of the tool or the confusion by introducing it, therefore it was not included in the results. After this 3rd session the participants received thorough feedback, so that we were sure that in session 4 we were really measuring the effect of using the design tools as intended.

The comparison of sessions 1 and 2 showed the effect of working together from the first moment in the process without having a supportive design tool, which led to an decrease in the average number of mentioned functions (-40%) as well as to a decreased number of mentioned sub solutions (-53%), see Fig 8. Between sessions 1 and 4 the effects of working together from the outset of the process and with a supportive design tool is compared with the traditional design approach in which the architects start alone and the other disciplines join in later. There is a clear increase in the number of mentioned functions (+61%) as well as the number of mentioned sub solutions (+105%), see Fig. 8.

From the analysis of the workshops it could be concluded that the number of functions and aspects considered, as well as the number of sub solutions 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. 8.

4.2 Student workshops
During the design sessions 1, 2 and 3 in the 2011, 2012 and 2013 versions of the Multidisciplinary master design project, students performed different design assignments which were based on the assignments tested in the workshops for professionals. Central element of the Integral Design process is the use of morphological charts by individual designers which were combined into one morphological overview by the design team. All the assignments were related to aspects of nearly Zero Energy Buildings and had a similar level of complexity to make the results of the different sessions comparable. The number of functions and sub solutions/proposals mentioned by the designers in their morphological charts and the
morphological overview of the design teams were counted and are represented in Fig. 9.

For the comparison of the results of the different workshops we looked only to the session 2 as session 1 was really a learning session for the students. Session 3 was used to experiment different additional interventions (stimulating creativity by C-K theory based tools (Zeiler 2012), adding a professional to a student’s team (Zeiler 2013)) which are out of the scope of this paper. The difference in their individual morphological charts between professionals and students relatively small for the number of mentioned functions (students 11% more). However, the number of generated solutions by the students is much higher than that of the professionals (33% more). On average the student teams (2011- 2013 MO) produced slightly less functions (4% less) and slightly more sub solutions (6% more) than the professional teams (2009 PhD MO). The results showed that the use of morphological overviews reduces the difference between professionals and students compared to the underlying difference in their individual morphological charts. In all groups the use of the morphological overviews led to an increase of functions (students + 21% and professionals +61%) as well of solutions (students +48% and professionals +105%).

5 Discussion

Designing nZEB requires that architect and engineers overlap their knowledge and skills and share the character of a designer (Brunsgaard et al. 2014). There is necessity for each discipline to cover basic and essential knowledge and skills of the others (Heiselberg 2007, Trebilcock 2009). Just putting the professionals together right from the beginning of the design process led to a decrease in the number of aspects and sub solutions, indicating a less effective design process. This is in line with literature about brainstorm experiments (Nystad et al. 2002 & 2003), were they also found out that by just bringing together more designers the productivity decreases compared with the results from individual sessions. The team needs a kind of guidance, in our case supplied through the Integral Design Method and its tools. As can be seen from the results of session 4, when professionals worked with the tool there is a large increase in the number of generated aspects and solutions by the design teams.

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. The advantage of our approach, which uses individual morphological charts transformable by the design team into a morphological overview, is that the design team’s discussion begins after the preparation of the individual morphological charts. This allows each designer to develop his own interpretation and representation, in relation with his specific discipline based knowledge and experience. This interpretation can then be combined with the interpretations by the other designers into a morphological overview. The different interpretations of the design brief results in a team specific morphological overview based on the morphological charts 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 summary, this approach permits greater freedom of mind of the individual designers and results in more functions and aspects generated through the individual interpretation of the design problem as well as the generation of more sub solutions from the different disciplines.

Through visualizing the individual contributions within a design team, morphological overviews based on the individual morphological charts stimulate the emergence of solution concepts within design teams. By structuring design (activities) and communication between design team members methodical design, morphological overviews as the basis for reflection on the design results helps the design teams come forward with new design propositions. Design processes can be improved through improving three types of process communication (Senescu et al. 2013, Senecu and Haymaker 2013): understanding, sharing and collaboration. The morphological overview supports the communication within the design team and leads to better understanding, sharing and collaboration.

Although the proposed model of methodical design, as a basis for integral design, has an implicit proposition which tends to portray integral design as mere problem solving across various professional domains, is has to be emphasized that the reflection by means of the morphological overview enables the introduction of creativity beyond the mere functional, decompositional approach. The model behind much design process methods is a problem solving process that is tackled by procedural knowledge (Lawson 2005). However, as stated by Lawson, this is a very poor model and the human design process is more one of reflective practice (Schön 1983). This is why we emphasize the use of the Morphological Overview as reflective element crucial to the design process.
The activation of design team member’s knowledge through a priming manipulation such as the use of morphological overviews leads to the generation of more (sub) solutions. However, there is an uncertain relation between quantity and quality. The most parsimonious interpretation of the quantity-quality relation is chance; each generated idea has an equal probability of being a good idea. Therefore, according to the laws of chance, the number of good ideas produced should increase in relation to the total number of ideas produced (Rietzschel et al. 2007).

The focus within methodical design is on technical solutions between different groups of professionals and could help users play a role to build on the social acceptability of these solutions at the design stage. Although the results are based on a limited set of experiments, and took place in a workshop setting, we think that the conclusions will hold for the professional practice from discussions with the Dutch professional organizations for architects and engineers. As our developed design workshops series is based on experiences from practice, there might of course be different design constraints in the real world, like budget, different interests of the stakeholders and other commercial considerations. So, in the real world different designers could be more reluctant to share their ideas in such an open and transparent way. However, the Integral Design workshops were part of the permanent professional educational program of BNA (Royal Institute of Dutch Architects). Therefore it is presumed that the conclusions are relevant. At the end of the workshops, the participants were asked to fill in a questionnaire about the use of morphological overviews during the design sessions, see Fig. 10.

The participants were quite positive about their experience using the morphological overview. One of the participating architects at the workshop, Carl-Peter Goossen, became so enthusiastic about the design approach that he made it his leading principle in the design and management of the projects at his company; BouwQuest (Goossen, 2010a &b). A good example of his work is the Veldhuizerschool in Ede (AgentschapNL, 2011). It is the first new passive house primary school in the Netherlands. The construction of the school was finished in July 2011.

6 Concluding remarks

The main lessons from the paper is that integral design with its use of morphological overviews stimulate the emergence of new sustainable design concepts for nearly Zero Energy Buildings in addition to helping
architects and engineers with their new roles within building design teams. Our integral design method with its workshops is a useful tool to support and structure communication between architects and engineers in the conceptual design phase. This is a good tool for supporting the education of a new generation of architects and engineers, who each have new roles in the design of sustainable nearly Zero Energy Buildings.

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Figure 1. The stages of building design (den Hartog 2003)

Figure 2. Shift in focus towards early design phases especially conceptual design. (Leutgöb, 2013)
Figure 3. Four-step pattern of Integral Design

Figure 4. First two steps leading to the first column with functions/aspects to be fulfilled and sub-solutions of the morphological charts

Figure 5. Building the morphological overview; Step 1, the MO contains the chosen functions and aspects (1) from the different MC’s. Step 2, the MO with the accepted sub-solutions (2) from the separate MC’s
Figure 6. (A) Mental model concept (Badke-Schaub et al 2007) and (B) Design Team mental model Morphological Overview in analogy with the model by Badke-Schaub (Zeiler 2014)

Figure 7. The four different design sessions
Figure 8. 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

Figure 9. The average number of functions and part solutions mentioned in the morphological charts and morphological overview of the design

**Figure 10.** Ratings of professionals regarding the use of morphological overviews

<table>
<thead>
<tr>
<th>Morphological overviews are relevant for:</th>
<th>Average professionals</th>
</tr>
</thead>
<tbody>
<tr>
<td>(on 1-10 scale)</td>
<td></td>
</tr>
<tr>
<td>Number of participants</td>
<td>43</td>
</tr>
<tr>
<td>Response questionnaires in %</td>
<td>91</td>
</tr>
<tr>
<td>The use of morphological overview increased the number of</td>
<td>6,8</td>
</tr>
<tr>
<td>generated alternatives</td>
<td></td>
</tr>
<tr>
<td>The use of morphological overviews supported the team</td>
<td>7,2</td>
</tr>
<tr>
<td>design process</td>
<td></td>
</tr>
<tr>
<td>The use of morphological overview lead to an increased</td>
<td>7,4</td>
</tr>
<tr>
<td>insight in the contribution of ‘others’</td>
<td></td>
</tr>
<tr>
<td>The use of morphological overview lead to improved</td>
<td>7,2</td>
</tr>
<tr>
<td>communication within the design team</td>
<td></td>
</tr>
</tbody>
</table>
Author