Integral design: a new necessary professional skill for architects and HVAC-engineers to cope with their new roles for sustainable development
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Integral design: a new necessary professional skill for architects and HVAC engineers to cope with their new roles for sustainable development.

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INTRODUCTION

Energy consumption by buildings accounts for around almost 40% of the total energy in the EU and US (Juan et al 2010). 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. Sustainable development was brought into mainstream conservation on a global scale (Rivera 2009). However the concept of sustainability is not something new, in 1987 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 Commission).

Attempts were made to develop international consensus about 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 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 need to be met (Holzer 2009). New approaches are needed and the construction industry is in the early stages of a revolution to reinvent the design process that was used before the large scale application of HVAC systems (Heiselberg 2007). Such an integral design approach can eventually lead to an integral process, team and method. All the required conditions for innovation of the end product the building (Seppanen et al 2007).

The main body of the paper starts (section 2) with the development of the Integral Design (ID) method: a design method that helps to merge the different perspective of all designers and engineers involved in the design process. The derived design method workshops for professionals, architects and engineers in building design was tested in practice. This is described in section 3. In section 4 the results are presented of the application of the ID-method within the workshops. A discussion about using the developed ID-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.

METHODOLOGY

"We were both looking at the same thing, seeing the same thing, talking about the same thing, thinking about the same thing, except he was looking, seeing, talking and thinking from a completely different dimension."

(Robert M. Pirsig)
The need for another design approach

Sustainability is a crucial issue for our future and therefore the European Directive 2002/91/EC requires practitioners to provide buildings with design solutions that comply with minimum energy performance requirements, while safeguarding thermal comfort (Mazzeo et al 2008). Architecture has an important role to direct sustainable development (Taleghani et al 2010). Sustainable building designs need to provide solutions for sustainability issues ranging from flexible use to renewable energy, energy reduction measures while maintaining and even increasing comfort level of the users.

In building design the roles are changing of architects and traditional discipline based consulting engineers. Engineering consultants have to do more than just 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 could make significant improvements in the areas of sustainability and energy consumption. In the capacity as engineering consultants they should draw up the pre-conditions to which architect must adhere in their designs (DGMR 2011). However, the only right solution for improving the overall quality of building design can be found within the design team itself and letting the design team functions as a real team. This means for each member within the design team equal respect for the role of each team member, though still with its own discipline based expertise. However proper design tools and working methods are needed which could help architects in the design process (Kanters et al 2012). 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 called 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 mostly the early engagement of engineers in the process as a clear sign of this (Kanters et al 2012). This early collaboration with engineers was found to be crucial for sustainable architecture like solar integrated architecture. However, this collaboration in the conceptual design phase was not always easy for the architects (Kanters et al 2012): engineers 'spoke another language', were often 'too specialised', and 'not willing to compromise on certain issues'. So clearly, the building design process becomes more heterogeneous, with several diverse actors involved such as architects, engineers, contractors and clients. Given the existing disparities in the construction industry, King (2012) stated that in order to do anything meaningful in terms of moving to low carbon society, we need a consistent framework, design method, within which we can apply knowledge embodied in a design team.

Integral Design

However, in building design one has to work with ill-defined problems were the wanted solution and the problem itself develops almost in parallel at the early stages of the design process. Also the amount of relationships and dynamic social interactions makes it increasingly complex. Therefore a method is needed to structure this wicked problem (Simon 1969). In the early sixties research started to investigate new design methods as a way to improve the outcome of design processes. Since then there was a period of development (Cross 2007, Chai and Xiao 2012), however there is still no clear picture about the ideal design method (Bayazit 2004) and many models of designing exist (Wynn & Clarkson 2005, Pahl et al. 2006, Ranjan et al 2012, Gericke and Blessing 2012). In the Netherlands Methodical Design was a quite familiar design method (Zeiler and Savanovic 2009). The methodical design process is a framework application-independent principle 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. This methodical design method was extended into an Integral Design model by us by adding a fourth process step with a special focus on selection to the original three step process. So a distinctive feature of the integral design model is the four-step pattern of activities (generating,
synthesizing, selecting and shaping, see Fig. 1, that occurs on each level of hierarchical functional abstraction with the design process.

[FIGURE 1 OMITTED]

Another change to the original methodical design method is the intensified use of morphological charts developed by Zwicky (1948a) to support design activities in the design process (Savanovic 2009). A morphological chart is a kind of matrix with columns and rows which contains the things to solve and the possible solutions connected to them. Different overall solutions are created by combining various solution principles to form a complete system combination (Olvander et al. 2008). Within the Integral Design process a morphological chart is formed by decomposing the main goals of the design task into functions and aspects, which are then listed on the first vertical column of the morphological chart. The functions and aspects are derived from the program of demands. Possible solution principles for each function or aspect are then listed on the horizontal rows of the corresponding function or aspect, see Fig. 1 B for the concept of a morphological chart.

In the first step of the integral design method the individual designer has to make a list of what he thinks are the most important functions that have to be fulfilled based on the design brief and put it into the first column of the morphological chart, see Fig. 2A. In the second step of the process the designers adds possible part solutions to each aspect or function in the rows after the specific function or aspect, see Fig. 2B.

[FIGURE 2 OMITTED]

Using a morphological chart is an excellent transparent way to record information about the solutions for relevant functions and as such an 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 plays a central role in the integral design approach for design teams. Each participant of a design team develops a full morphological chart from their own specialist point of view, see Fig. 3.

[FIGURE 3 OMITTED]

These individual discipline based morphological charts can be combined to one overall morphological chart, called morphological overview. The morphological overview of an integral design team process is 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 come up with their solutions for these functions and aspects to fill in the rows within the morphological overview.

EXPERIMENTS

After extensive experiments with different set ups for implementing the Integral Design approach, in which well over one hundred professionals participated (Savanovic 2009), it was concluded that a good way to test our design approach was a workshop setting for professionals. Therefore workshops were arranged as part of a training program for architects and consulting engineers (structural engineers, building services engineers and building physics engineers) (Savanovic 2009). 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 in total 14 series of workshops were organized in which in total more than two hundred experienced professionals from these organizations, with at least 10 years of experience, voluntarily participated.

The 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 have been used in all workshops. In the workshops stepwise changes were introduced

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in the setup of the design sessions to the traditional building design process type, in which the architect starts the process and the other designers join in later in the process, see Fig. 4. After each session the teams were rearranged to avoid learning effects between team members.

[FIGURE 4 OMITTED]

The first two design sessions on day 1, provide reference values for the effectiveness of the involved of all designers from different disciplines right from the start. On the second day the morphological overviews were introduced. The application of morphological overviews during the setup of the third design session enabled structuring of design functions/aspect and the generated (sub) solution proposals. Additionally, the third setting provided the possibility of one full learning cycle regarding the use of morphological overviews. After the feedback to the participants about their use of morphological charts and the morphological overview all teams had the basic knowledge to apply them correctly in the fourth setting. During the design sessions 1, 2 and 3 in the 2011 and 2012 versions of the multidisciplinary master design project, students performed different design assignments which were based on the assignments tested in the workshops for professionals. Characteristic 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. This enabled us to compare the results of the students with those of the professionals.

RESULTS

Here only a brief selection of the results of the professional workshops is given. More results and information were presented by Savanovic (2009). Session 3 was a learning session, in which the designers had to apply morphological charts (MC) and morphological overview (MO) and afterwards got a thorough feedback to make sure that in session 4 the real effect of the design tools were measured. Therefore it is not included in the results, see Fig. 5.

[FIGURE 5 OMITTED]

The comparison of session 1 and 2 showed the effect of starting working together from the first moment in the process without having a supportive design tool led to an increase in the average number of mentioned functions (-40%) as well as to a decreased number of mentioned sub-solutions (-53%), see Fig 5. Comparing the effect of working together from the first moment in the process with a supportive design tool (session 4) with the traditional design approach in which the architects start alone and the other join in later (session 1), there is a clear increase in the number of mentioned functions (+65%) as well as the number of mentioned sub-solutions (+107%), see Fig. 5. However, this increase is not for all individual disciplines as can be seen from the results from session 1 (without tools) compared with the results of session 4 (with use of morphological charts and morphological overview), see Fig. 6A. The effect of the design intervention is different for each discipline per example there is a decrease of outcome for architects and building physics engineers but an increase of outcome by building services engineers, structural engineers and for the design team as such, see Fig. 6 B.

[FIGURE 6 OMITTED]

For the comparison of the results of the different workshops we looked only to the session 2 of the student workshops within the master project Integral Design, session 1 was the learning session for the students. On average the student teams (2011-2013) produced slightly less functions but more subsolutions than the professional teams (Savanovic 2009), see Fig. 7.

DISCUSSION

New design methods are needed to improve the present situation in building design. A process approach is needed in which the intentions of the client are transparently linked to the building design-
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*Figure 7. Number of functions and subsolutions proposed in the morphological charts and morphological overview by students from the Master project Integral design, compared with the results from the professionals*

<table>
<thead>
<tr>
<th>MC Functions</th>
<th>MC subsolutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students 2013</td>
<td>6,4</td>
</tr>
<tr>
<td></td>
<td>22</td>
</tr>
</tbody>
</table>
### Table: MO Functions and MO Subsolutions

<table>
<thead>
<tr>
<th>Group</th>
<th>MO Functions</th>
<th>MO Subsolutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students 2012</td>
<td>8,7</td>
<td>28,7</td>
</tr>
<tr>
<td>Students 2011</td>
<td>5,1</td>
<td>16,3</td>
</tr>
<tr>
<td>Average students</td>
<td>6,6</td>
<td>21,8</td>
</tr>
<tr>
<td>Professionals</td>
<td>5,2</td>
<td>14,8</td>
</tr>
<tr>
<td>PhD 2009</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Table made from bar graph.