Integral Design method developed and tested in Industry and being taught at University

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Abstract

A supportive design method was developed in cooperation with the Dutch professional organizations of architects and consulting engineers. The design method provides overview and helps to structure the communication and reflection between design team members. The design method is focused on sustainability and the creation of sustainable solutions in the conceptual phase of building design. After testing the method in workshops as part of a training program in industry, the design method was transferred and applied at the department of architecture for master students for their multidisciplinary Master project Integral Design. The workshops became part of the permanent professional education program of the Dutch society of architects, several in-company workshops for industry were held and a course is now being taught at the Faculty of the Built Environment to architects and engineers in a workshop as part of a Master project Integral Design. In these workshops student teams have to learn to design together. During the last part of the workshop, experienced professionals join the student teams to take part in the design process. This is a rather unique experience for the students. So the partnership with building industry let to the developed design support method which acted as a kind of tool to close the gap between University and Industry.

Keywords: Integral Design, Industry, University, Partnerships with business.

1 Introduction

In response to climate change and 'peak oil' architecture should encompass the environmental task of design a low carbon built environment (Chen et al. 2011). 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). 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 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: engineers 'spoke another language', were often 'too specialised', and 'not willing to compromise on certain issues'. In some cases, the consulting engineers representing all kind of different disciplines outnumbered the architects in a design meeting, which made the architect feeling uncomfortable (Kanters et al. 2012). 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 within which we can apply knowledge embodied in a design team. The different viewpoints imply a need for cooperation: a collaborative approach to the design process. The constant and radical changes which characterizes modern world makes it (Williams et al. 2010), as Dineen & Collins (2005) observed, impossible: 'to base our future on the certainties of the past. Unable to define what we need to know, we have begun to focus on how we will need to know, on the flexibility and openness which characterizes creative thinking'. Creative collaborations that cross disciplinary boundaries are essential to innovation and the occurrence of boundary spanning, where ideas from one domain, discipline or functional area are imported into another (Joyce et al. 2010), in a way that solves new problems or presents new solutions (Burt 2004). However, just putting people with diverse perspectives and from different disciplines in the same room is no guarantee that effective boundary-spanning collaboration will occur (Joyce et al 2010). In the past many design methodologies were developed at universities however design methodologies find less or slow industrial

applications (Gill 1990, Eder 1998, Frost 1999, Birkhofer et al. 2005, Stolterman 2008, Tomiyama et al. 2009). There for one of our main objective was to develop it in industry and then to implement it back at the university. If it works in industry it is also something of value to teach our students so that are well prepared for industry. Each year we evaluate the results of the method and try to find ways to further improve it. One of these interventions was the adding of a professional to a student team. The assumption was that this would lead to an improved result and a different design process. For the students it was also a good opportunity to see professionals in action. This made it also possible to focus on the differences between professionals and students in the phase of conceptual design.

The main body of the paper starts (Section 2) with the development of the Integral Design (ID) method: a design method that helps to merge the different perspective of all designers and engineers involved in the design process. The core of this method is the use of morphological charts. By combining morphological charts of each individual building design discipline, a morphological overview is created. This morphological overview represents the interpretation of the design task and the design knowledge within the design team related to the design task. The main aim of the ID-method approach is to improve conceptual design (the process level) in order to increase the potential for creation of innovative integral design concepts (the product level). The derived design method workshops for professionals, architects and engineers in building design was tested in practice and then implemented in the curriculum of the university. 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 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.

2 Methodology

In design one has to work with ill-defined problems where the wanted 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 it increasingly complex. Therefore a method is needed to structure this wicked problem (Simon 1969). In the early sixties due to problems with the quality of products and projects people started to investigate new design methods as a way to improve the outcome of design processes. Since then there was a period of expansion through the 1990s right up to day (Cross 2007, Chai & Xiao 2012), however there is still no clear picture (Horváth 2004, Bayazit 2004) and many models of designing exist (Wynn & Clarkson 2005, Pahl et al. 2006, Howard et al. 2008, Tomiyama et al. 2009). In the Netherlands Methodical Design is a quite familiar design method (Blessing 1994). This design method was extended into an integral design model by us by adding an evaluation step and adding the use of a design team's morphological overview based on the individual designer's morphological charts to support design activities in the design process (Zeiler & Savanovic 2009, Savanovic 2009). The morphological chart, as developed by Zwicky (1948), is formed by decomposing the main goal of the design task into functions and aspects, which are listed on the first vertical column of the chart, with related sub solutions listed on corresponding rows. The functions and aspects are derived from the program of demands. Possible solution principles for each function or aspect are then listed on the horizontal rows. The use of morphological chart is an excellent way to record information about the solutions for the relevant functions and aid in the cognitive process of generating the system-level design solution (Wynn & 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. Each participant of a design team develops a full morphological chart from their own specialist point of view, see Fig. 1. Different overall solutions are created by combining various solution principles to form a complete system combination (Ölvander et al. 2008). In principle each combination between different sub solutions from each function forms in the MC is a possible solution which results in enormous amounts of alternatives.

These individual, discipline based MC's can be combined to one overall MC, called morphological overview (MO). 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 by in the first column of the MO. 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 MO. Putting the MC's together enables to 'put on the table' the individual perspectives from each discipline about the interpretation of the design brief and its implications for each discipline. This supports and stimulates the discussion on and the selection of functions and aspects of importance for the specific design task, which than can be put into the design team's MO.

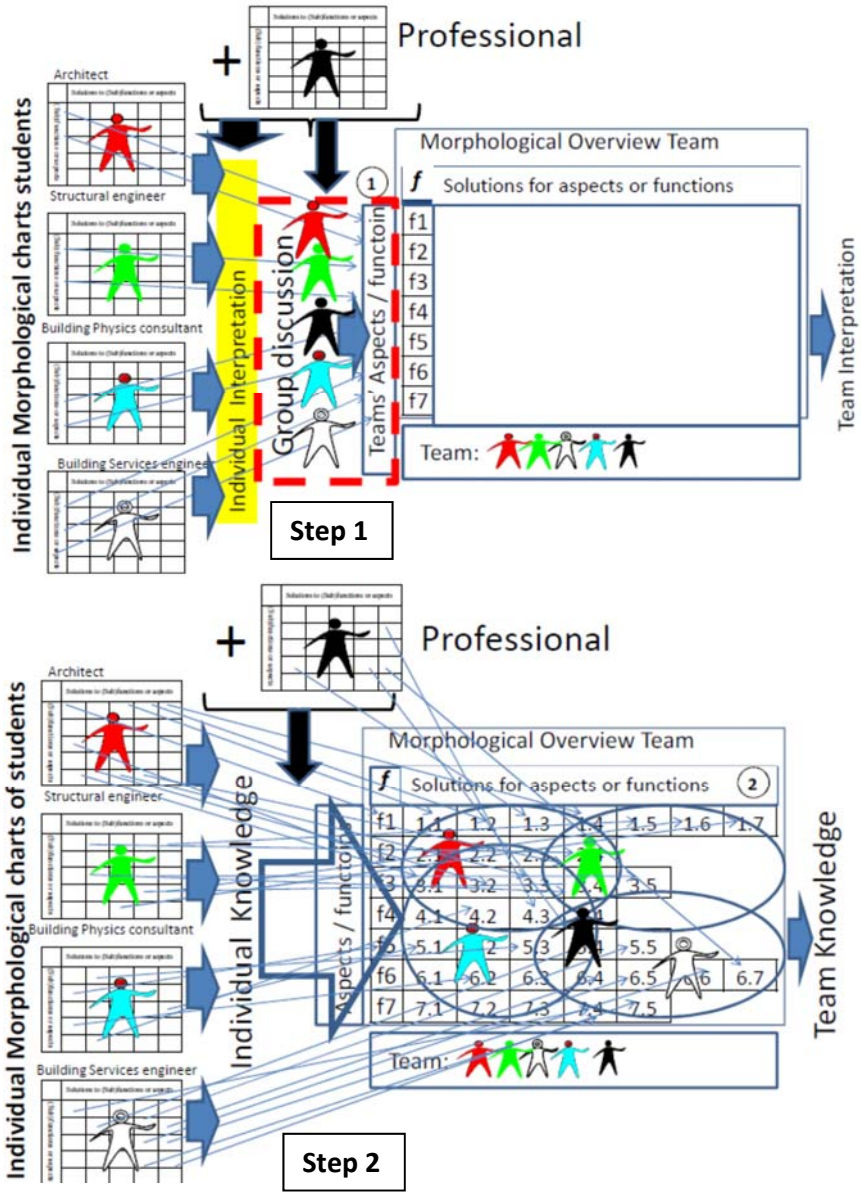


Figure 1: Building the morphological overview; Step 1 the MO contains the chosen functions and aspects (1) from the different MC's. Step 2 the MO with the accepted sub solutions (2) from the separate MC's

3 Experiments

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, with at least 10 years experience, from these organizations, voluntarily participated. After extensive experiments with different set ups for implementing the Integral Design approach, in which well over one hundred professionals participated, 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), as well as for architects and contractors (Quanjel 2013). These design exercises were derived from real practice projects and as such were as close to professional practice as possible. The design tasks during the two days are on the same level of complexity and have been used in all workshops. 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. In the final series of the research focussing on the interaction between architects and

engineers during the conceptual design phase three different design set ups of participants were tested in four sessions;

- Session 1 traditional design setting architect start and after a while the other designers/consultants join the process
- Session 2 all design team members start at the same moment together
- 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
- 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

In connection with the Integral design research project for professional in the Dutch building industry, we developed an educational project, the master project integral design. Interaction between practice, research and education forms the core of the 'integral approach'. Therefore the concept of the integral design workshop for professionals was implemented within the start-up workshop of our multidisciplinary masters' project. The basis 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 overviews. The different design assignment all were related to the design of zero energy buildings. These complex tasks require early collaboration of all design disciplines involved in the conceptual building design. The participants of the workshops were master students of the faculty of architecture, building and planning (architects, structural design, building physics and building services) and had an average age of 22 and no working experience. During 2011 in sessions 1 and 2 participated 29 students and in session 3 and 4 participated 27 students. In 2012 participated 22 students in the sessions 1 and 2 and in session 3 and 4 participated 20 students. In addition in session 3 and 4 six professionals participated, one in each student team, who were on average 50 years old and had around 25 years experience. The teams existed out of different disciplines and were changed after each session. The teams formations for the different assignments were changed from teams of two (session 1) to teams of four (session 2) and teams of five or six (session 3). Also the teams were formed so that all students worked together only once. During the morning of the second day, they had to perform design task 3 together with one professional expert in each group.

4 Results

Professional workshops

Here only a brief selection of all the results of the professional workshops is given. More results and information were presented by Savanovic (2009). Only the results of sessions 1, 2 and 4 will be discussed. This because session 3 was a learning session for the participants to get used to the design approach, in which the designers had to apply morphological charts (MC) and morphological overview (MO). Therefore it was not included in the results. After this 3th session the participants got a thorough feedback, so that we were sure that in session 4 we were really measuring the effect of the design tools. 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 decrease in the average number of mentioned functions (minus 40 percent) as well as to a decreased number of mentioned sub solutions (minus 53 percent). In session 4 the team's used the design method and when compared with session 1, the traditional approach, this led to an increase of the number of mentioned solutions of not less than plus 104 percent!

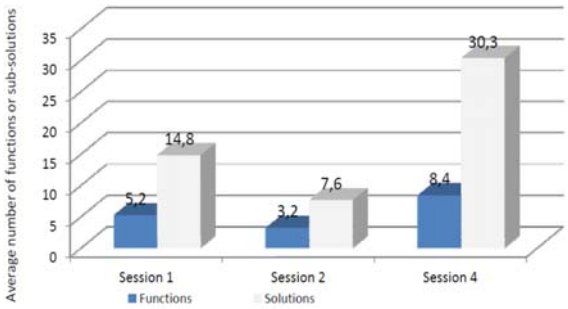
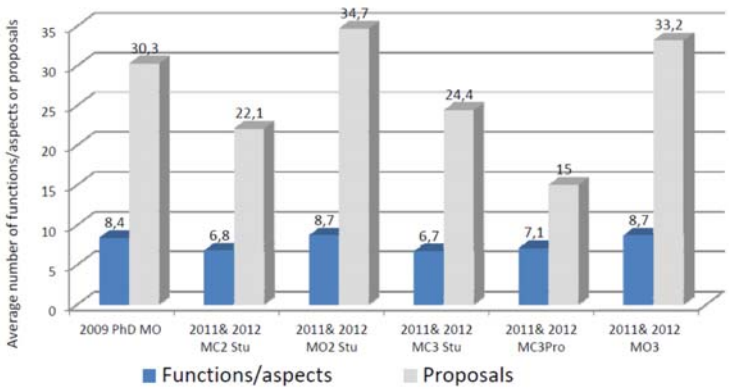


Figure 2: The average number of functions and sub-solutions generated by the professionals in the different sessions of the workshops Integral design (Savanovic 2009)

Student workshops

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. 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. Al 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. In session 3 the student design teams were joined by a professional. By making combinations within the morphological overview of possible sub solutions and combining them to overall solutions, the teams generate their solutions. The number of functions and sub solutions/proposals mentioned by the designers in their morphological charts were counted and are represented in Fig. 3.



MC=Morphological chart, MO=Morphological Overview, Stu=students, Pro=Professionals

Figure 3: The average number of functions and part solutions mentioned in the morphological charts and morphological overview of the design session 2 and 3, professional workshops 2009 and student workshops 2011 & 2012.

For the comparison of the results of the different workshops we looked only to the sessions 2 and 3 as session 1 was really a learning session for the students. On average the student teams (2011 & 2012 MO2 Stu) produce slightly more functions and sub solutions than the professional teams (2009 PhD MO). Adding one professional to a student team (2011 & 2012 MO3) slightly decreases the student design teams' performance level compared to the all student teams (2011 & 2012 MO2 Stu). The number of on average mentioned functions stays the same with 8.7 but the number of generated proposals decreased from 34.7 to 33.2 (a reduction of minus 4.3 percent).

For the workshop of 2012 we looked into more detail at the knowledge exchange between professionals and students as a result of the use of the MC's and MO. Quite remarkable is the difference between the percentage of functions/aspects and proposals mentioned by the individual professionals in their MC's and those finally used in the MO of the design team. Especially for the mentioned functions/aspects by the professionals there is quite a high difference: from 13 up to 60 percent and on average 34 percent, see Fig 4.

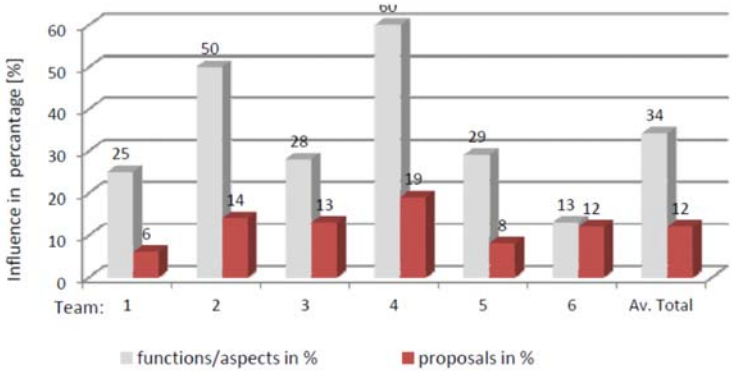


Figure 4: Percentage influence of by a professional mentioned functions or solutions in their morphological charts related to those listed in the final design team's morphological overview

In reaction to the influence factor we also looked at the effectiveness of professionals versus students. Effectiveness hereby defined as the ratio between the number of mentioned functions/aspects or proposals mentioned in the individual MC's versus the number which are actually accepted into the MO of the design team, see Fig 5 and 6. Quite remarkable is the fact that there was almost no difference in the average effectiveness of mentioned proposals in the MC's by the students (0.34) and professionals (0.36), see Fig 5 & 6. The professionals are more effective in the functions that they mentioned in the MC's compared to the students: 0.48 for the professions versus 0.25 for the students.

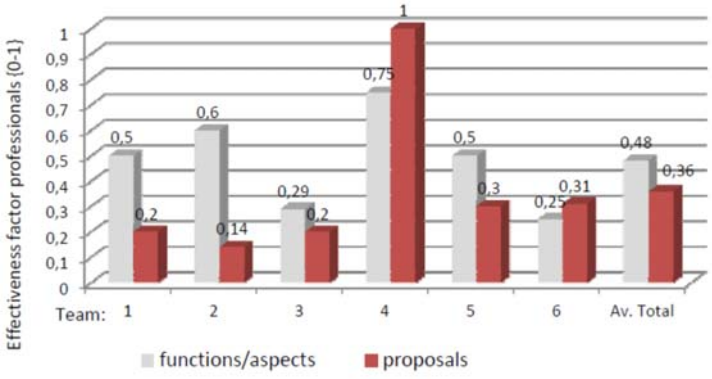


Figure 5: Effectiveness professionals: the number of mentioned functions/proposals in the MC's related to those in the MO

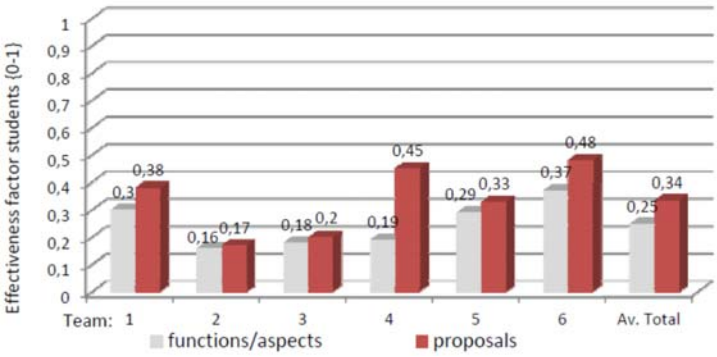


Figure 6: Effectiveness students: the number of mentioned functions/proposals in the MC's related to those in the MO

5 Discussion

New approaches are needed to bridge the gap between the worlds of theory and practice in building industry which look at designing as a process in which the concepts of function, behavior and shape of artifacts play a central role (Vermaas & Dorst 2007). Such integral design approach can eventually lead to an integral process, team and method all the required conditions for innovation of the end product: the building (Seppänen et al. 2007). To try to improve the current building design practice in the Netherlands we choose Methodical Design as developed by van den Kroonenberg as a starting point, as it is based Systems theory and on a synthesis of the German and Anglo-American design models of the mid seventies and as such has exceptional characteristics (Zeiler & Savanovic 2009). This formed the basis for extension of the Methodical Design method into Integral Design.

Although the use of morphological charts based on functional decomposition is quite common in mechanical engineering design, they are rarely used in a multi-disciplinary way besides the mechanical engineering domain. The advantage of this approach is that the discussion begins after the preparation of the individual morphological charts. This allows each designer to develop his own interpretation and representation, in relation with his specific discipline based knowledge and experience. This interpretation than can be combined with the interpretations by the other designers into a morphological overview. The different interpretations of the design brief result in a team specific morphological overview based on the morphological charts chart from each design team member. Importantly, this encourages and allows engineering based disciplines to think and act more freely than is common in the traditional design approach. In sum, this approach allows a greater freedom of mind of the individual designers and results in more creativity in interpretation of the design problem and generation of sub solutions from the different disciplines.

We researched how for student design teams, interventions to the integral design method could improved the quantitative outcome of the design process. One intervention was tested to stimulate the creativity of design teams within the integral design process: the adding an experienced professional to the student teams. Not only the reflection by the teachers to the (part) results of the students but more the active participation of the professionals might have a stimulating effect on the students and increased their productivity in design alternatives. In industry we see that often the young inexperienced designers are mentored by some of their old colleagues. Therefore we thought it was a good idea to combine young designers with a more experienced professional at the beginning of a

large design project in an educational setting. However, this intervention had a limited positive effect on the increased number of generated solutions and as such had a small stimulating effect on the creativity of students within the integral design process. However, we did not yet look into the qualitative effects of the intervention. This something for further research.

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

Although our developed university design course is based on experiences from practice there are of course major different design constraints in the real world, like budget, different interests of the stake holders involved and other commercial aspects. So in the real world the different designers could be more reluctant to share their ideas in such an open and transparent way. This would have a severe effect when compared to real building planning.

6 Concluding Remarks

At the TU Eindhoven an Integral Design method (ID-method) has been developed in close cooperation with industry. In workshops with experienced professionals the ID-method was developed and tested in practice in cooperation with the Dutch society of Architects and the Dutch society of consulting engineers (Savanovic 2009, Quanjel 2013). The primary goal of this research was to find a way for an integral approach to building design in which architecture with different engineering disciplines merge into a multidisciplinary design team. Integral design method enables to merge different perspectives of all designers, involved in the design process. In the conceptual phase of integral design, a morphological overview represents the design team's interpretation of the design task and the related design knowledge and as such it defines the problem and solution space of the design task. After the development and testing in industry the design method was implemented in the master education of the Faculty of Architecture of the TU Eindhoven in the master project Integral Design. In this project students of different disciplines (architecture, structural engineering, building physics, building technology and building services) have to design a highly complex net Zero Energy Building. Right at the beginning of the master project integral design project, the design method was offered to the students to integrate in a meaningful way engineering and architectural insights, knowledge and experience. In a two-day workshop some introduction lectures are given and the students have to perform some hands-on exercises. The results show that the Integral Design-method is relevant to stimulate understanding and knowledge exchange between design team members. This makes it easier to create new solutions for buildings which have to fulfil more and more complex demands. The setting of the workshops allows us to further investigate interventions in the design process of students. One of these interventions was the introduction of a professional to the student's design teams during the workshop. However, the effect of this intervention proved to be rather limited to the quantitative outcome of the design process.

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