

Integral Design: the new roles for architect and engineers for sustainable development

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Abstract

The built environment is one of the most important areas to work on for sustainable development. The built environment uses 40% of our energy for operating as well as another 8% embodied energy by the used building materials and their production process. To fulfil the demand for Zero Energy Buildings there is a need for synergy between the architectural and engineering domain. New strong demands for a more sustainable built environment led to a more complex design process. To cope with this complexity architects need more support from specialized engineers. The different expertise of engineers must be used more effectively especially in the conceptual design phase to reach for new solutions. This has consequences for the role of the engineers involved; they have to operate early in the conceptual building design process and act more as designers and less as traditional calculating engineers. As a consequence engineers have to develop new skills. Also the architect has to learn to not only share his ideas in the conceptual design phase but to really open up his mind and to truly design together with the engineers. Important is that no longer the architect is the one that leads the design process but that the team of architect and engineers leads the design process: Designing becomes a team effort already in the conceptual phase of design. To support these diverse multidisciplinary building design teams we developed a supportive design method in cooperation with the Dutch professional organizations of architects and consulting engineers. This design method is based on the use of morphological charts and a morphological overview. It helps architects and engineers with their new role in the conceptual design phase as it enables to structure each perspective on the design task as well as to structure the available domain knowledge. 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. In these projects student teams consisting of architects and engineers had to design net Zero Energy Buildings. In the last 7 years several Master Projects Integral design were held and there was a continuous development to optimize the cooperation between architects and engineers. Our design method showed that it is possible to engage engineers and let other disciplines learn from them within the conceptual building design phase.

1 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 came aware of the problems related to this energy consumption and sustainability as Al Gore sounded the alarm bells with his ‘inconvenience 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, already 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 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). 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).

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.

2 Methodology: Integral Design

2.1 The need for another design approach

In building design the role 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 functioning 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: 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.

2.2 Integral Design

In design one has to work with ill-defined problems where 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 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 and Xiao 2012, Le Masson et al. 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, 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 design method was extended into an Integral Design model by us by the intensified use of morphological charts developed by Zwicky (1948) to support design activities in the design process (Zeiler and Savanovic 2009, Savanovic 2009). The morphological chart 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 and Clarkson 2005, Ritchey 2010). The morphological chart (MO) 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.

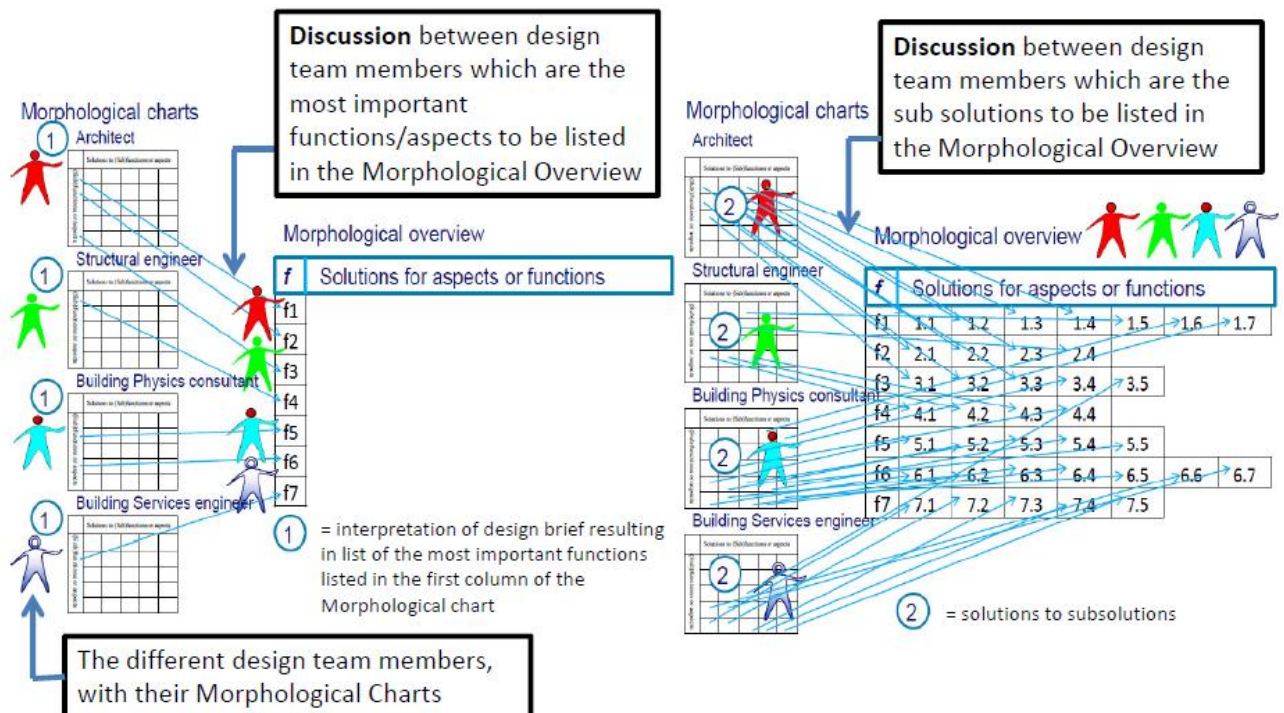


Figure 1. Building the morphological overview; Step 1 the MO contains the chosen functions and aspects (1) from the different MC's. Step 2 the MO with the accepted sub solutions (2) from the separate MC's

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 by 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. Putting the morphological charts 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, see Fig. 1.

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.

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. 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. 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.

4 Results

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. 1. Sessions 3 was a learning session to get used to the design approach, in which the designers had to apply morphological charts (MC) and morphological overview (MO). Therefore it is 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.

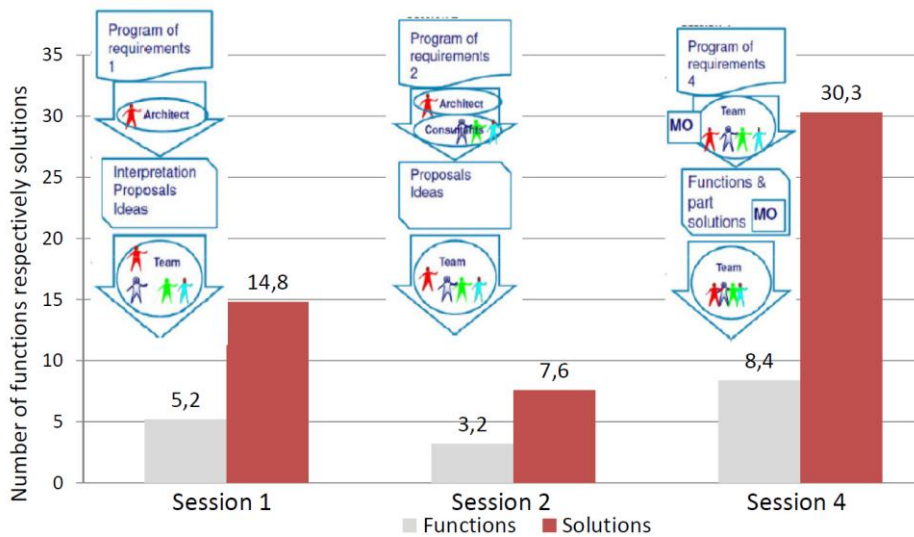


Figure 2. Comparison of the number of aspects/functions and the number of partial solutions being generated by the design teams in design sessions 1, 2 & 4 of the final workshops series

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 (-40%) as well as to a decreased number of mentioned sub solutions (-53%), see Fig 2. Between session 1 and 4 the effect of working together from the first moment in the process but then with a supportive design tool is compared with the traditional design approach in which the architects start alone and the other join in later. There is a clear increase in the number of mentioned functions (+65%) as well as the number of mentioned sub solutions (+107%), see Fig. 2.

From the analysis of the workshops it could be concluded that, the number of functions and aspects considered, as well as the number of subsolutions 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. 3. The effect of the design intervention is different for each discipline par 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. 4.

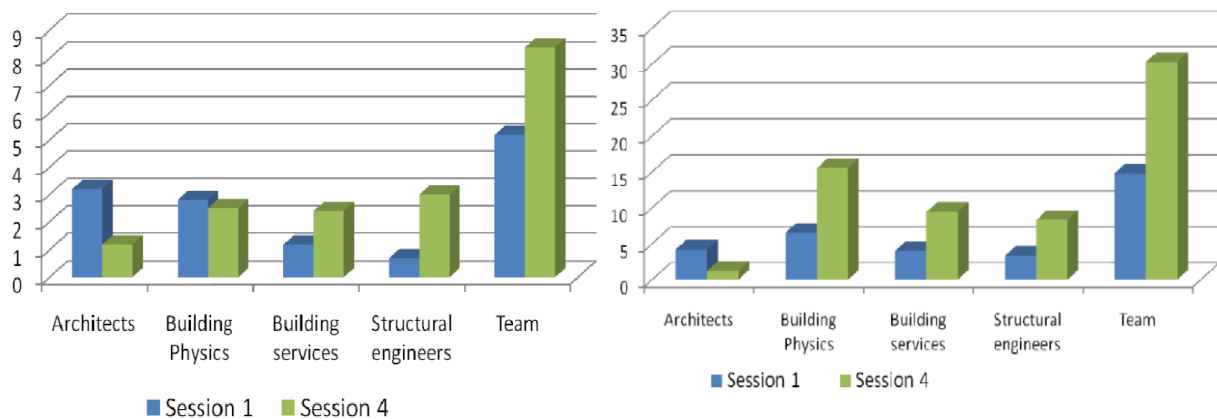


Figure 3. Average number of functions proposed by a discipline during session 1 and 4 of the 4th workshops series and Figure 4. Average number of subsolutions proposed by a discipline during session 1 and 4 of the 4th workshops series

For the comparison of the results of the different workshops we looked only to the sessions 2 session 1 was really a learning session for the students. On average the student teams (2011/2012 MO2Stu) produce slightly more functions and sub solutions than the professional teams (2009 PhD MO), see Fig. 5.

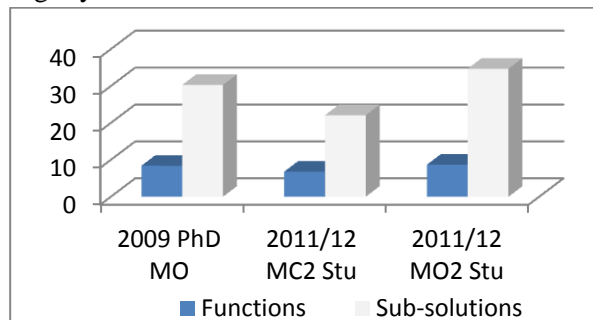


Figure 5. Average number of functions/sub-solutions proposed by designers/design teams during session 2 of the student workshops where they worked with morphological charts and morphological overview

5 Discussion

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 and 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.

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 a uncertain 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 workshops with experienced professionals a first prototype of the ID-method was developed integrating four key elements: design team, design model, design tool and design setting. The ID-method was developed and tested in practice in cooperation with the Dutch society of Architects and the Dutch society of consulting engineers. The primary goal of this research was to find a way to integrate architecture with different engineering disciplines into an integral design process for net Zero Energy Building design. Right at the beginning of such integral building design project, a design method was offered to integrate in a meaningful way engineering knowledge and experience. The results show that the Integral Design-method is relevant for increased insight between design team members, which makes it easier to create net Zero Energy Building-concepts. 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. Master students from architecture, building physics, building services, building technology and structural engineering participated in the project.

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References

- Bayazit N., 2004, Investigating Design: A review of Forty Years of design research, *Design Issues* 20(1), 16-29
- Blessing L.T.M., 1994, A process-based approach to computer supported engineering design, PhD-thesis Universiteit Twente.
- Chai K-H., Xiao X., 2012, Understanding design research: A bibliometric analysis of Design Studies (1996–2010), *Design Studies* 33(1): 24-43
- Cross N., 2007, Editorial Forty years of design research, *Design Studies* 28(1), 1-4
- DGMR 2011. Accessed May 16th 2011 <http://www.dgmr.nl/en/building-physics/>
- Gericke K., Blessing L., 2012, An analysis of design process models across disciplines, Proceedings International Design conference Design 2012, Dubrovnik
- Hansen H.T., Knudstrup M.A., 2009, The development of a tool for Sustainable Building Design: Facilities investigation of the creative space, Proceedings 26th Conference on Passive and Low Energy Architecture, Quebec
- Heiselberg P., 2007, Integrated Building Design, DCE Lecture Notes No.017, Aalborg University
- Holzer D.C.C., 2009, Sense-making across collaborating disciplines in the early stages of architectural design, PhD thesis, School of Architecture and Design Design and Social Context Portfolio, RMIT University, October 2009

- Horváth I., 2004, A treatise on order in engineering design research, *Research in Engineering Design* 15(3), 155-181
- Howard T.J., Culley S.J., Dekonick E., 2008, Describing the creative design process by the integration of engineering design and cognitive psychology literature, *Design Studies* 29(2): 160-180
- Juan Y.K., Gao P., Wang J., 2010, A hybrid decision support system for sustainable office building renovation and energy performance improvement, *Energy and Buildings* 42:290-297
- Kanters J., Horvat M., Dubois M., 2012, Tools and methods used by architects for solar design, *Energy Buildings* <http://dx.doi.org/10.1016/j.enbuild.2012.05.031>
- King D., 2012, Holistic Approach, *CIBSE Journal* January 47-49
- Le Masson P., Hatchuel A., Weil B., 2012, How design theories support creativity – an historical perspective, *Proceedings 2nd International Conference on Design Creativity, ICDC2012, Glasgow*
- Lee J., Jeong Y., 2012, User-centric knowledge representations based on ontology for AEC design collaboration, *Computer-Aided Design* 44:735-748
- Pahl G., Beitz W., Feldhusen J., Grote K.H., 2006, *Engineering Design, A Systematic Approach*, 3th ed., Ken Wallace K. and Blessing L. translators, Springer
- Quanjel E.M.C.J., 2013, Collaborative Design support, PhD thesis TU Eindhoven
- Ranjan B.S.R.C., Srinivasan V., Chakrabarti A., 2012, An extended, integrated model of designing, *Proceedings of TMCE, Karlsruhe*
- Rezgui Y., Hopfe C., Voarkulpipat C., 2010, Generations of knowledge management in the architecture, engineering and construction industry: An evolutionary perspective, *Advanced Engineering Informatics* 24: 219-228
- Rietzschel E.F., Nijstad B.A., Stoebe W., 2007, Relative accessibility of domain knowledge and creativity: The effects of knowledge activation on the quantity and originality of generated ideas, *Journal of Experimental Social Psychology* 43: 933-946
- Ritchey T., 2010, Wicked problems Social messes, *Decision Support Modelling with Morphological Analysis*, Swedish Morphological Society, Stockholm
- Rivera A., 2009, International Application of Building Certification Methods: A comparison of BREEAM and LEED, *Proceedings 26th Conference on Passive and Low Energy Architecture, Quebec*
- Savanović P., 2009, Integral design method in the context of sustainable building design, PhD thesis, Technische Universiteit Eindhoven
- Seppänen O., Steenberghe T. van, Suur-Uski T., 2007, Energy Efficiency in Focus – REHVA workshops Clima 2007, REHVA Report No.2
- Simon H. 1969, *Sciences of the artificial*, MIT Press, Cambridge.
- Tomiyama T., Gu P., Jin Y., Lutters D., Kind Ch., Kimura F., 2009, Design methodologies: Industrial and educational applications, *CIRP Annals – Manufacturing Technology* 58(2), 543-565
- Vermaas P.E., Dorst K., 2007, On the conceptual framework of John Gero's FBS-model and the prescriptive aims of design methodology, *Design studies* 28(2), 133-157
- Wynn D., Clarkson J., 2005, Models of designing, in *Designing process improvement*, eds. Clarkson J., Eckert C., Springer
- Zeiler W., Savanović P., 2009, General Systems Theory based Integral Design Method, *ICED'09, Stanford*.
- Zwicky F., 1948, Morphological Astronomy, *The observatory* 68(845), 121-143