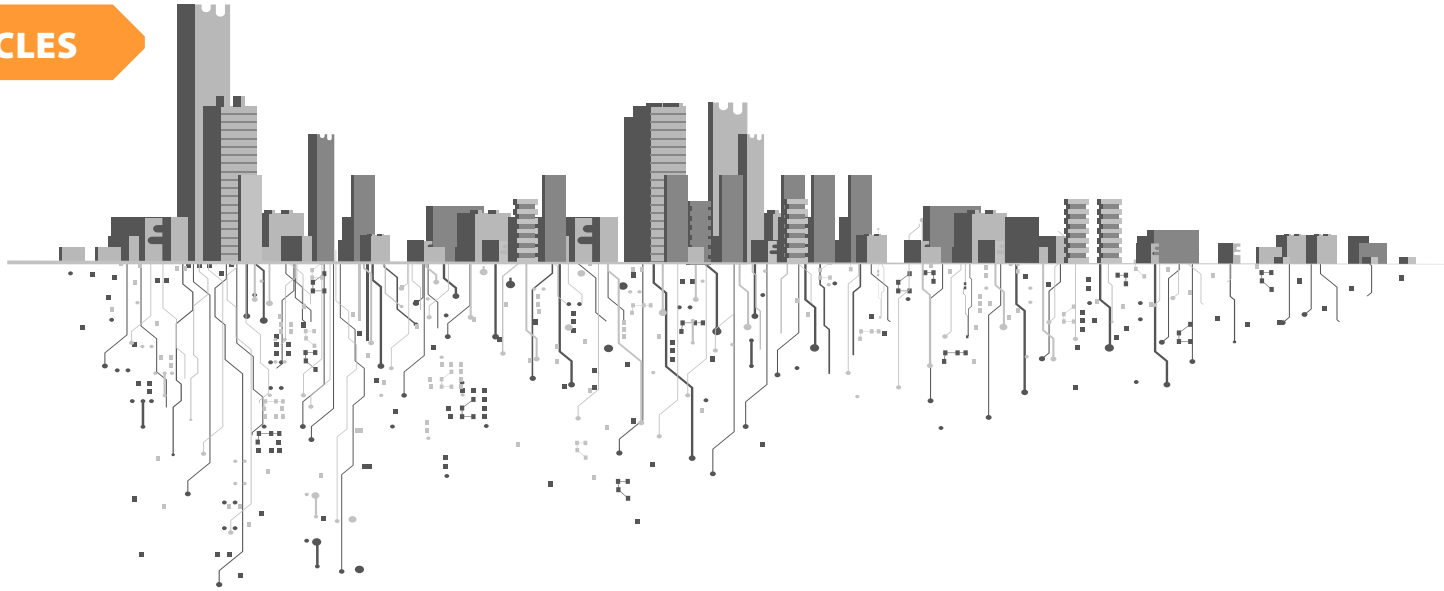


Integral design – a necessity for sustainable building design

© Vincent van den Hoogen

WIM ZEILER
Faculty of Architecture and the Built Environment, Eindhoven University of Technology, Eindhoven, the Netherlands
w.zeiler@bwk.tue.nl

Due to the rising demand for more sustainable buildings, it is essential to make optimal use of natural resources. However, therefore it is necessary to end the dichotomy between architecture and technology leading to far from optimal functional buildings responsible for high operational and failure costs. To close the gap between technology and architecture, it is time for integral design. The necessity for this was recognized by the Dutch Royal Society of Architects, BNA, as well as the society of Dutch consulting engineers, NL Engineers, and the Dutch Building Services society, TVVL. A design methodology was developed and implemented in the education curriculum of the Technical University of Eindhoven. In this paper, the method and the added value for the professional domain will be presented.

Keywords: Integral Design, Collaborative conceptual design

Introduction

"Architecture will become more informed by the wind, by the sun, by the earth, by the water, and so on. This does not mean that we will not use technology. On the contrary, we will use technology even more because technology is the way to optimize and minimize the use of natural resources" [Richard Rogers]

Collectively, buildings in the EU are responsible for 40% of our energy consumption and 36% of greenhouse gas emissions, which mainly stem from construction, usage, renovation, and demolition [EU 2020]. Global warming and the depletion of materials and resources are major problems. There is a clear need to change the way how buildings are designed and not try to solve the problems using the same kind of approach/logic that caused them in the first place.

The concept of a building, the basic design, is conceived by the architect first, then there is room for other disciplines. Design of buildings is seen largely as an individual's creative act. However, more and more it is realized that effective collaboration during the concept design phase in architecture provides the greatest potential for the overall success of a building project [Leon et al 2014]. This is not really a new idea as already Le Corbusier one of the most famous architects of the last century showed, see **Figure 1**.

The design of a highly sustainable building, due to the increased complexity of building design [van der Linder et al 2016], inevitably calls for more design collaboration in the conceptual design phase as well. Only the early open collaboration of architects and engineers can facilitate the creation of the necessary new knowledge and solutions beyond the specific scope of each individual discipline [Kovacic and Fitzmoser 2014]. According to the Royal Institute of British Architects (RIBA) president Jane Duncan, architects, engineers, and builders must collaborate [CIBSE 2016]. Designing Sustainable Buildings needs synergy between the architectural and engineering domain to create new solutions. This innovation is needed to reduce the environmental load caused by buildings. A holistic planning process is required in order to reduce the high complexity and achieve a goal-oriented procedure during the planning of buildings and the development of integrated systems [Honold et al 2019]. However, in comparison to conventional buildings, such adaptive sustainable buildings require much higher planning effort and an interdisciplinary planning team with disciplines that have typically not been involved in building planning thus far [Honold et al 2017].

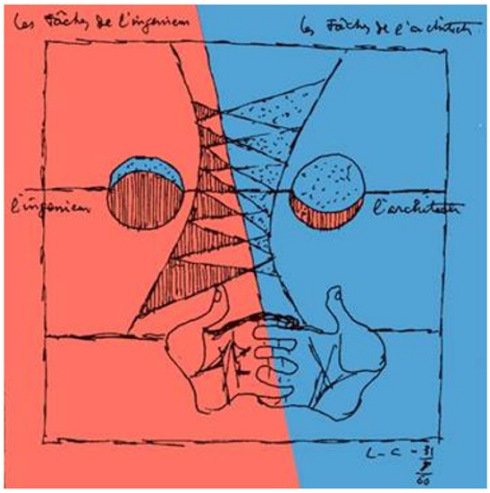


Figure 1. Necessary change in relationship between Architect and Engineer. (Source: Le Corbusier 1960)

Norman Foster and the design board at Foster + Partners are strong supporters of sustainable design and are keen to interpret and integrate engineering principles within design concepts [Smith 2019]. Their philosophy is that the best projects arise from a totally integrated approach to the design process, where the core disciplines work together to conceive and design a project from its earliest inception [Jackson and Heywood 2019]. Clearly, Building Design is a team effort, teamwork is key therefore it is necessary to create a place for the needed innovation. The benefits of the integrated design are better decisions, higher speed of response, and improved ability to iterate and thus reduce the complexity. Early engagement is essential within building design teams.

However, just putting all disciplines together is not enough, there is a clear need for design support to facilitate collaboration between the various design team members from different disciplines. Design deals with complex ill definite wicked problems which are difficult to solve. Therefore, it is important to give designers the right tools as well as a supportive process framework to order the design process. However, in the field of architecture, there is a lack of a body of theory to support the study of architectural design methods [Plowright 2014], which makes it necessary to review concepts from other foiled of study like mechanical engineering. Therefore, we looked for a framework to support the activity of building design. In the early 1960s researchers and practitioners began to investigate new design methods to improve design process outcomes [Cross 2007] right up to the present day [Le Masson et al 2017].

Integral Design where the architect and consulting engineers truly collaborate in the conceptual phase of the building design process is needed is an optimal exchange of interpretations and ideas, see **Figure 2**.

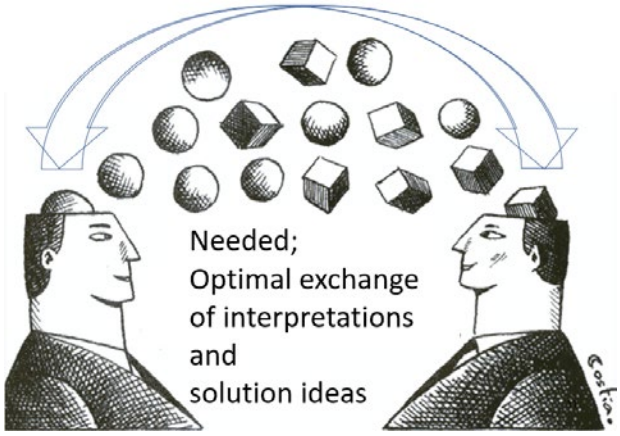


Figure 2. The needs with the conceptual design phase.

In section 2, details of the developed methodology are described. In session 3 the experimental setting was provided to improve the design process and descriptions of the experiments for testing the method and interventions with professionals and with students. In section 4, the results of the different experiments are provided, in section 5 the analysis of the results is followed by a discussion of the results in section 6. Finally, section 7 provides the conclusions about the added value of the design approach as an educational support tool and research tool as well as some remaining needs for further research and developments in relation to the morphological aspects of the developed design tools. This article is an updated overview of an earlier published paper [Zeiler 2016] and represents the result of research on Integral Design that started in 1999 up to now.

Methodology

It is important to provide a theoretical basis to encourage the strategic use of design methodologies as teaching strategies [Curry 2014] fully and strictly applied in industrial applications [Dorst 2016]. It is better to develop a design method as close as possible to practice and with help of industry. Therefore, in 1999 the professional Dutch organization for architects BNA and consulting engineers NL Ingenieurs together with the University of Technology Delft and the Dutch Building Services Society started research in close cooperation with the industry to develop a design method to improve the conceptual building design process. This led to research with workshops organized with professional organizations to test a specific design method, see **Figure 3**. Integral Design based on Methodical Design and the extensive use of Morphological Charts and Morphological Overviews [Savanovic 2009].

The Integral design method is based on in the tensive use of morphological charts [van den Kroonenberg 1988] and its outcome was evaluated in a situation as close as possible to practice amongst professionals. The design method has a distinctive feature, the step pattern of activities (generating, synthesizing, selecting, and shaping, that occurs within the design process, see **Figure 4**.

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. This is derived from their own specialist perspective. 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 and is then put

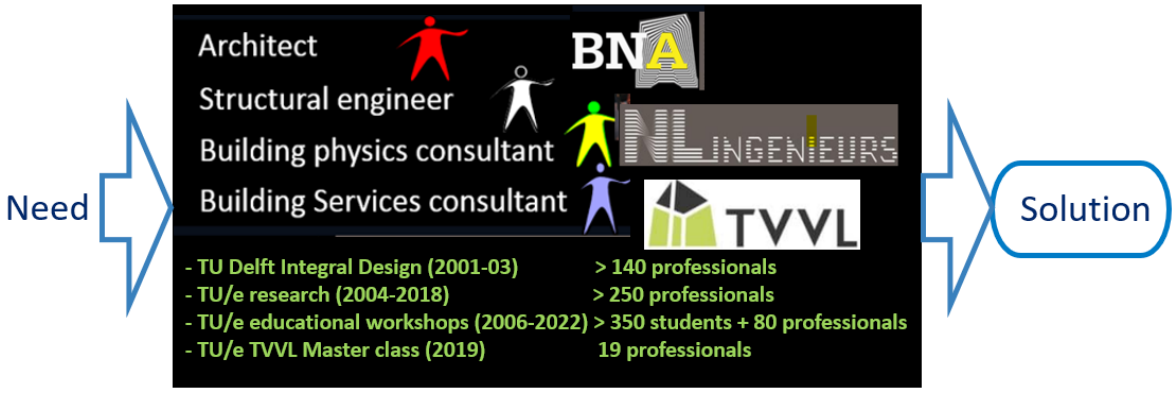


Figure 3. Black-box approach to building design with all professional organizations involved.

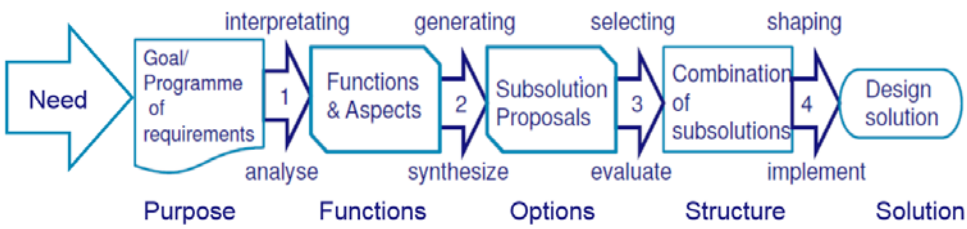


Figure 4. Basic steps within the Integral design process.

into the first column of the morphological chart, see **Figure 5**. A morphological chart is a kind of matrix with columns and rows which contain the aspects and functions to be fulfilled, see **Figure 5** step 1 and the possible solutions connected to them, see **Figure 5** step 2. These functions and aspects are derived from the program of demands. In principle, overall solutions can be created by combining various sub-solutions to form a complete system solution combination [Ölvander et al 2008].

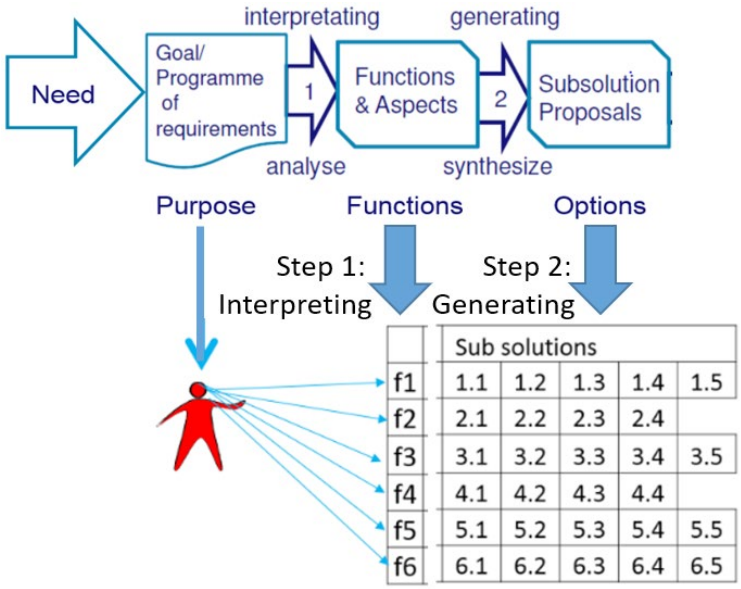


Figure 5. Concept of a morphological chart: Step 1 Functions and aspects to be fulfilled and step 2 related sub-solutions to the functions and aspects.

In the second step of the process, the designers add the possible part solutions to the related rows of the functions/aspects of the first column, see **Figure 6** Step 2i. The morphological charts represent the individual interpretation of reality, leading to active perception, stimulation of memory, activation of knowledge, and definition of the needs of each individual designer. These individual morphological charts can be combined by the design team to form one morphological overview, see **Figure 6**. This is done in two steps, the team members have to agree on what are the most important functions and aspects to be fulfilled see **Figure 6** step 1t. After this, the team can decide on which sub-solutions are relevant to be added to the agreed functions or aspects, see **Figure 6** step 2t. 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.

By structuring design (activities) with morphological overviews as the basis for reflection on the design results, stimulates communication between design

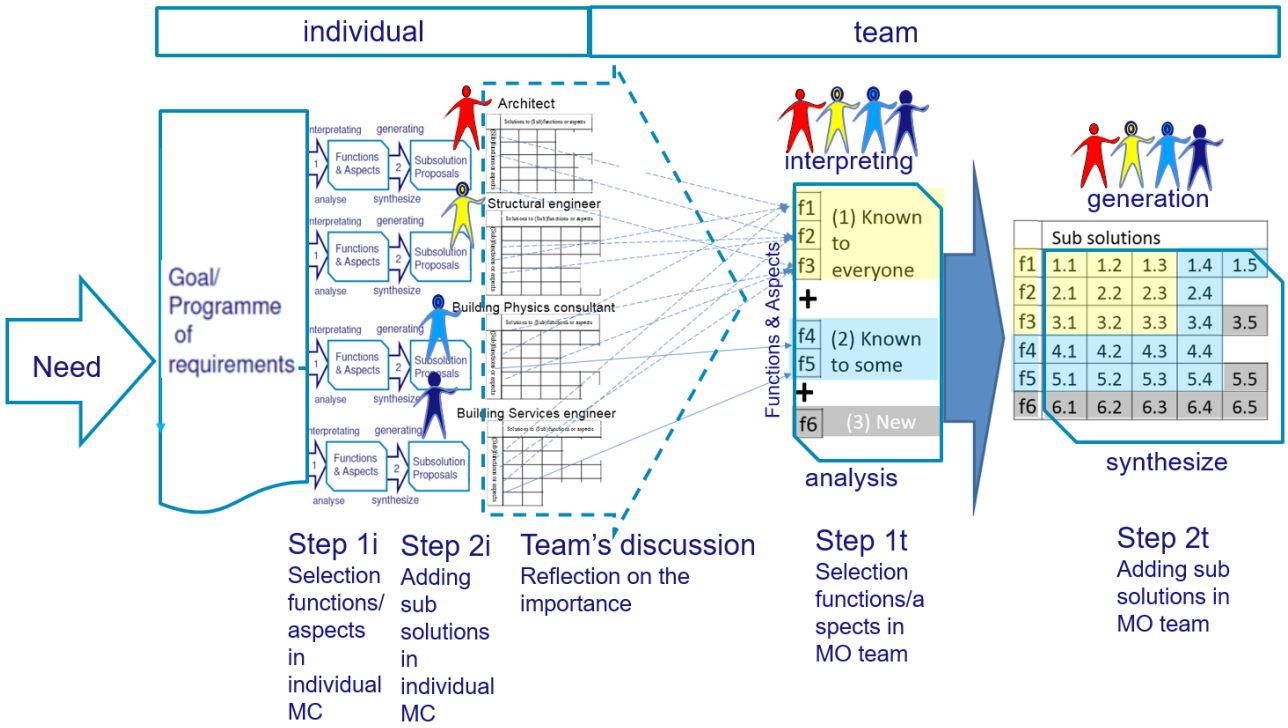


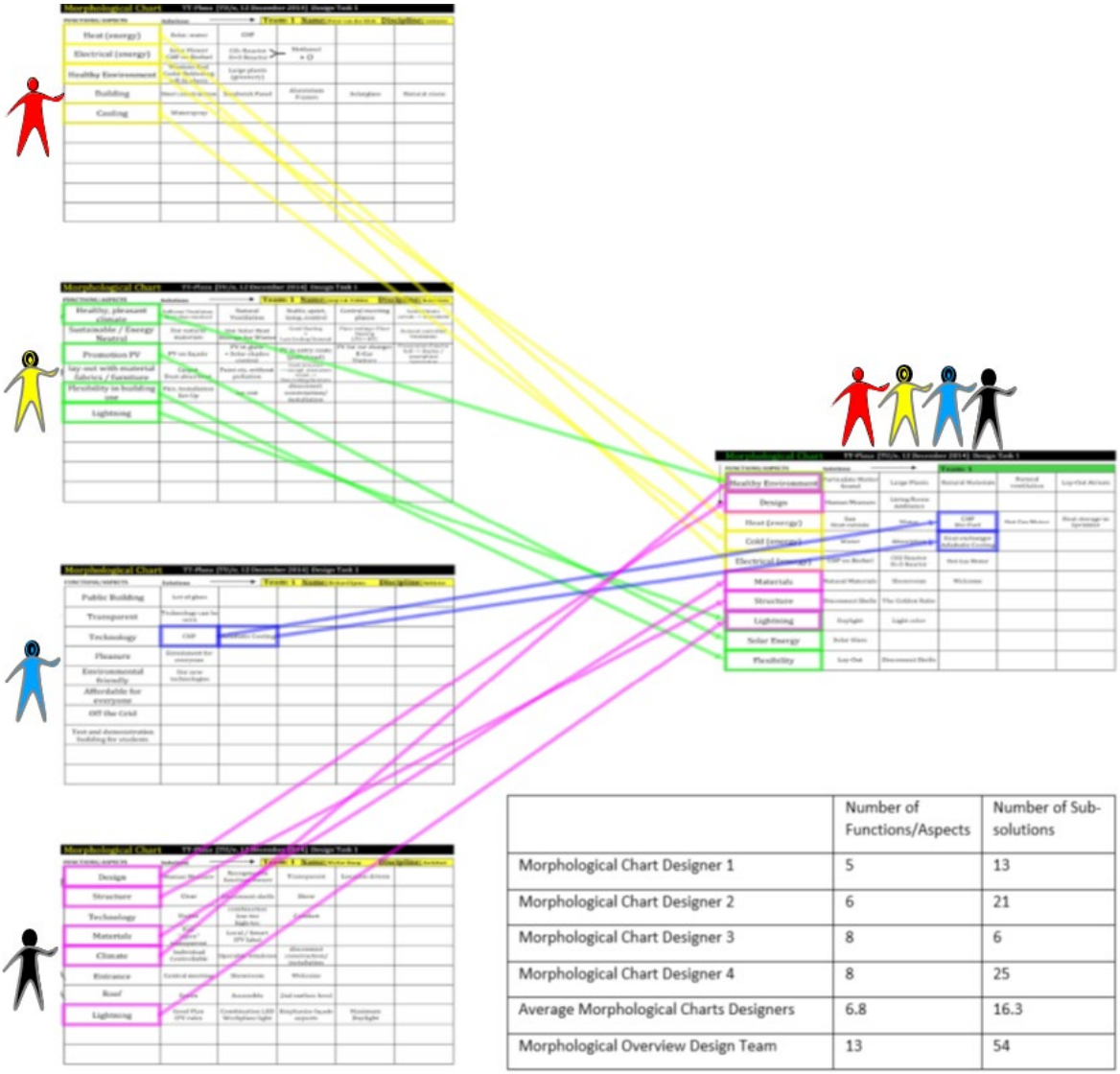
Figure 6. The first two design steps of the design team's process cycle, interpreting the design brief and list the functions in the first column of the individual morphological chart and the related sub-solutions.

team members and helps the understanding within design teams. It eases collaboration as it makes it easier to come forward with new design propositions. Visualizing the contributions, the morphological overview stimulates the understanding of the different perspectives among design team members.

Unfortunately, in the conceptual phase of the design, it is not possible to accurately evaluate the quality of the mentioned functions/aspects or sub–solutions. Only a quantitative analysis is possible by counting the number of mentioned functions/aspects and sub-solutions. The number of functions and sub-solutions mentioned by the designers in their morphological charts and the design team's morphological overview were counted, for example, see **Figure** 7.

Experiments

Since the year 2000, together with the Royal society of architects (BNA), the Association of Consulting Engineers (NLIngenieurs) and the Society of Building Services Engineers (TVVL), different series of workshops were organized in the Netherlands. More than two hundred professionals, with at least 12 years of experience, of the involved professional organizations, voluntarily participated in these workshops. After extensively experimenting with different setups for the workshop, a 2-day workshop setting was selected [Savanovic 2009]. The two days workshop was organized as part of a professional training program for architects and consulting engineers (structural engineers, building services engineers, and building physics engineers)



	Number of Functions/Aspects	Number of Sub-solutions
Morphological Chart Designer 1	5	13
Morphological Chart Designer 2	6	21
Morphological Chart Designer 3	8	6
Morphological Chart Designer 4	8	25
Average Morphological Charts Designers	6.8	16.3
Morphological Overview Design Team	13	54

Figure 7. An example of the transformation of the individual morphological charts into a morphological overview, indicate the functions/aspect in the morphological overview and where they came from [Zeiler 2018].

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. 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 zero energy buildings. These complex tasks require early collaboration of all design disciplines involved in the conceptual building design and as such let the students experience the added value of the design method. Master students from architecture, building physics, building services, building technology and structural engineering participated in these projects. The basis of this project, which serves as a learning-by-doing start-up workshop for master students, is a method with extensive use of morphological charts combined to a morphological overview of the design team. During the start-up workshop, professionals participated in the student's design teams and this specific intervention within the design process has been investigated. Having a tested framework for introducing the design method allowed us to investigate the effects of different interventions as well as the analysis of several aspects, such as the effectiveness of different designers or the effect of communication in words or sketches. The framework of the approach is presented in **Figure 8**, the program and setup of the workshop.

All the assignments had a similar level of complexity which made the results comparable. To investigate the effect of the morphological tools of the Integral design approach they were used in similar workshop setting for different types of students, professionals, and practitioners, in brackets is the number of participants;

Bachelor students (181) 2015-2022

The students of the course in which the workshop was held were 2nd and 3th year bachelor students, age around 20-22, all Dutch. The students were from the Faculty of the Built Environment and of the Faculty of Psychology and Technology.

Master students (150) 2011-2018

These were 4th-year students (architectural, structural, building physics, and building services) all from the Faculty of the Built Environment, aged around 22-24.

Architectural Master students (11) 2017

One workshop was held for students of architecture all working in a Master thesis project design atelier as part of their MSc graduation project. So they were 5th-year students who nearly had finished their studies, aged around 23-25. This was the only mono-disciplinary group in the comparison.

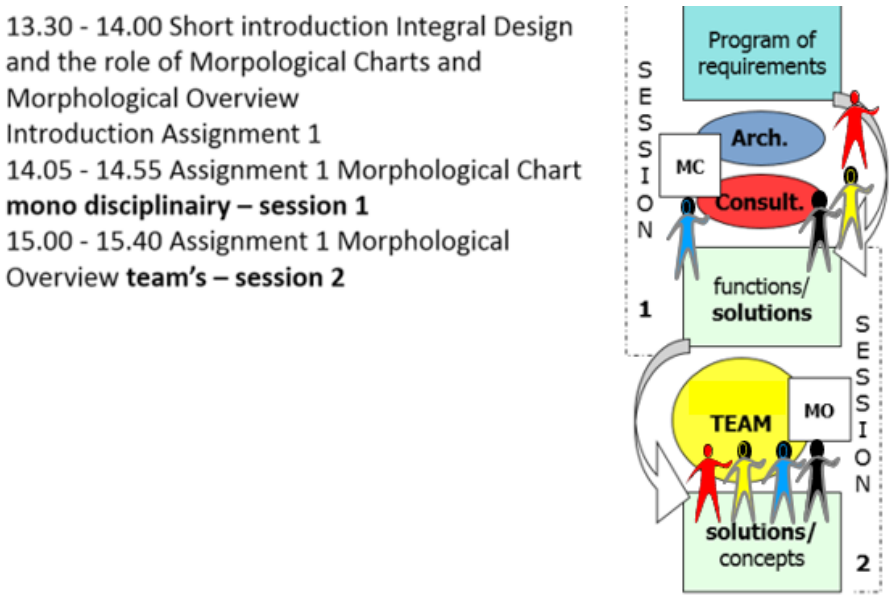


Figure 8. Program and set-up of start-up workshop.

PDEng students (18) 2012-2013

The students from the Post Doctoral Engineering (PDEng) program Smart Energy Buildings and Cities (SEB&C) were from all different International MSc discipline backgrounds, age 24-26.

Professionals (24) 2009

In the research of Savanovic [2009] the concept of working with morphological overviews was tested in different series of workshops for professionals, with at least 12 years of experience. There were 4 series of workshops with in total 96 participants for testing different set-ups. Here only the results of the final 5th workshop are included.

Professionals (8) 2015

In 2015, the researchers participated in the start-up of a real professional project for the design of a nearly Zero Energy Building [de Bont et al. 2016]. The professionals had around 20-year experience.

Practitioners (19) 2019

The Dutch society for Building Services Engineers TVVL, together with the TU Eindhoven organized a master call. There were no restrictions on the participants, unlike the workshops for professionals in the research of Savanovic [2009] where the participants should have a least 12 years of experience.

Results: From Morphological Chart to Morphological Overview

The 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. The average numbers of functions and solutions as mentioned by the design teams in their Morphological Charts and Morphological Overview as well as the relative increase are represented in **Figure 9**.

Discussion

The group interaction is of great importance during the conceptual design phase and has a clear positive effect on the number of functions and aspects discussed as well as on the number of generated sub-solutions. This was found by the original research with professionals [Savanovic 2009] as well as in the educational setting with different types of students, as well as in experiments in real projects and professional settings. Given the number of involved design teams in the series of workshops, with 347 students and 123 professionals as participants, there is a sound quantitative basis for the conclusion that it really helps to integrate the different design disciplines and create synergy.

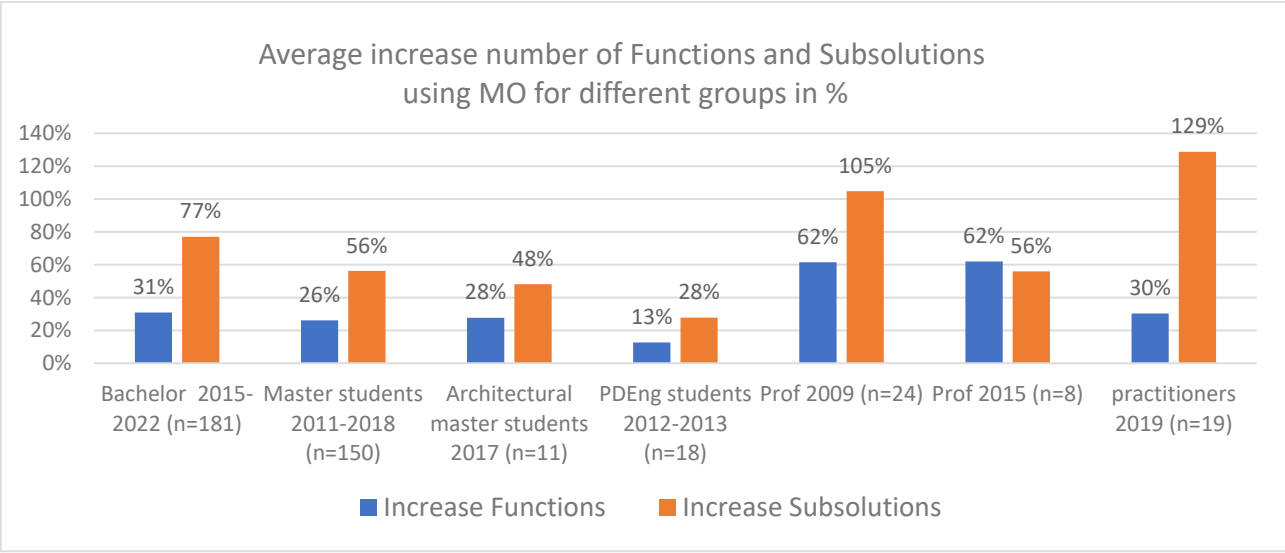


Figure 9. Comparison of the average relative increase in the number of functions and sub-solutions by individual students, professionals and practitioners in their Morphological Overviews compared to the average results from the individual Morphological Charts.

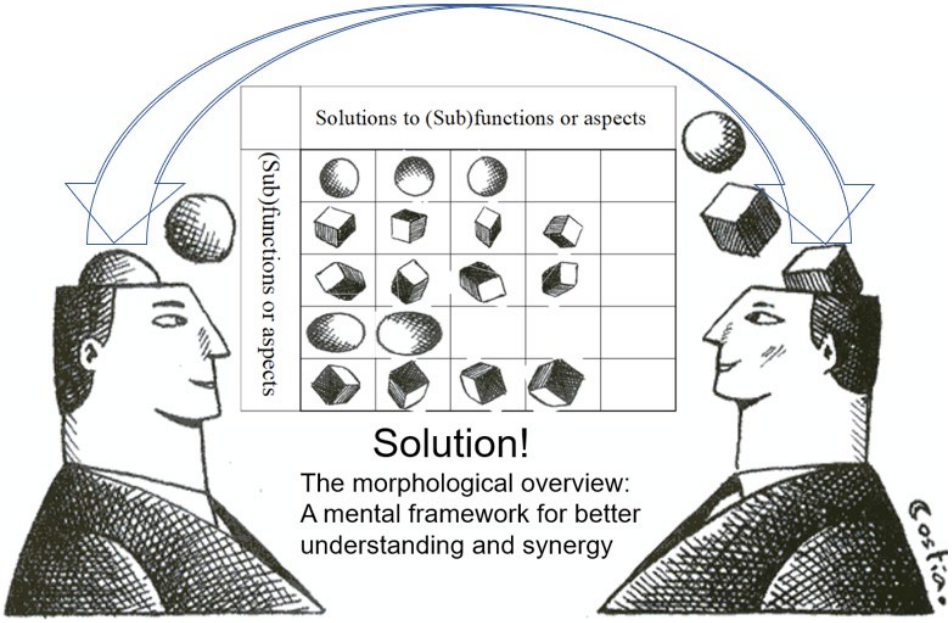


Figure 10. The morphological overview to connect the minds of the design team.

Conclusions

However, a break with the traditional line of thoughts of architects as well as consulting engineers is there for needed. A new design model, Integral Design, was developed to support interaction between all the disciplines involved in the conceptual building design process by structuring the communication and solution generation process in steps. By structuring the information flow about the tasks and solutions of the other disciplines the method forms a design within the design process and enables a structured approach even in the conceptual design phase. The use of the morphological overview based on the individual morphological charts creates a way to share interpretations and ideas for solutions forming a basis for synergy leading to more innovative designs, see **Figure 10**.

The main lessons from this paper are that Integral Design with its use of morphological overviews stimulates collaboration and exchange of ideas and perspectives between architects and engineers. It helps them with their communication. As such it is a good method for supporting the education of a new generation of architects and engineers, whom each have new roles in the highly complex tasks of designing sustainable nearly Zero Energy Buildings energy positive buildings or even Carbon neutral buildings.

The design method had a major positive effect on the number of proposed sub-solutions and also on the number of functions and aspects considered in the conceptual phase of the design process by the design team members. This indicates that the effectiveness and productivity of design teams were largely improved by adding structure to the process. The role of the morphological charts and overview is in structuring the process and enabling analysing the conceptual design process in more detail. As such is it a valuable approach to inventing the necessary new more sustainable solutions for the future. Integral design is a necessity for truly sustainable buildings and as such a prerequisite for the energy transition toward 2050. ■

Acknowledgements

This research was done in cooperation with the Dutch Society of Architects BNA, the Dutch Society for Consulting Engineers NLIngenieurs, and the Dutch Society for Building Services Engineers TVVL. The project was financially supported by the professional organizations Techniek Nederland (formerly UNETO-VNI) and Wij Techniek (formerly OTIB) as well as the foundations WOI and PIT.

References

CIBSE, 2016, RIBA president wants 'frank debate' on supply chain conflict, CIBSE Journal January 2016.

Cross N., 2007, Editorial Forty years of design research, Design Studies 28(1): 1-4.

Curry T., 2014, A theoretical basis for recommending the use of design methodologies as teaching strategies in the design studio, Design Studies 35: 632-646.

Davies M., 2014, I cannot think of a better career than services engineering, CIBSE Journal, April https://www.cibsejournal.com/general/i-cannot-think-of-a-better-career-than-services-engineering/.

Dorst K., 2016, Design practice and design research: finally together? Proceedings DRS 2016, Brighton, UK.

EU, 2020, Energy efficiency in buildings, https://ec.europa.eu/info/news/focus-energy-efficiency-buildings-2020-feb-17_en.

Honold C., Binz H., Roth D., 2017, Technical planning tasks and participants involved in planning Adaptive Buildings, Proceedings ICED 2017, Vancouver, Canada, 21.-25. August.

Honold C., Leistner S., Roth D., Binz H., Sobek W., 2019, Method Toolbox for the Multidisciplinary Planning and Development of Adaptive Buildings, Proceedings ICED19, Delft, The Netherlands, 5-8 August.

Kannengiesser U., Gero J.S., 2017, Can Pahl and Beitz' systematic approach be a predictive model of designing? Design Science, vol. 3, e24 journals.cambridge.org/dsj DOI: 10.1017/dsj.2017.24.

Kanters J., Horvat M., Dubois M., 2014, Tools and methods used by architects for solar design, Energy Buildings 68(part C): 721-731.

Kovacic I., Filzmoser M., 2014, Designing and Evaluation Procedures for Interdisciplinary BIM Use – An Explorative Study, Engineering Project Organization Conference Devil's Thumb Ranch, Colorado July 29-31.

Kroonenberg H.H. van den, 1988, Stimulating creativity and innovations by methodical design, In Creativity and Innovation: towards a European Network, Springer Netherlands.

Le Masson P., Weill B., Hatchuel A., 2017, Design Theory, Springer.

Leon M., Laing R., Malins J., Salman H., 2014, Development and testing of a design protocol for computer mediated multidisciplinary collaboration during the concept stages with application to the built environment, Proceedings DDSS 2014, Procedia Environmental Sciences 22: 108-119.

Linder V. van der, Dong H., Heylighen A., 2016, Capturing architect's designerly ways of knowing about users: Exploring an ethnographic approach, Proceedings DS 2016, Brighton, UK.

Pahl G., Beitz W., Feldhusen J., Grote K.H., 2007, Engineering Design, A Systematic Approach, third edition, Ken Wallace and Lucienne Blessing translators and editors, Springer.

Plowright P.D., 2014, Revealing Architectural Design: Methods, Frameworks & Tools, Routledge, London and New York.

Savanović P., 2009, Integral design method in the context of sustainable building design, PhD thesis, Technische Universiteit Eindhoven, Eindhoven, Netherlands.

Smith A., 2019, Piers' Review, Integrated design at Foster+Partners, CIBSE Journal, September, 40-42, https://www.cibsejournal.com/general/piers-review-integrated-design-at-foster-partners/.

Zeiler W., 2016, Integral Design to improve communication and sub-solution generation in building design collaboration, CIBSE Technical Symposium, Edinburgh, UK 14-15 April 2016.