Integral design a necessity for sustainable building design

Wim Zeiler

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

Abstract. Due to the rising demand for more sustainable buildings it is essential to make optimal use of the natural resources of sun, earth, water and wind. There is a urgent need saving energy and the necessity of zero or even energy positive buildings in the near future. However, therefor it is necessary to end the dichotomy between architecture and technology. This dichotomy leading to far from optimal functional buildings with poor indoor comfort and health conditions and also being responsible for high operational and failure costs. To close the gap between technology and architecture, between science and art, it is important to no longer subordinate to architecture but part of architecture itself. Instead of integrated design it is time for integral design. Architect and engineer working really together within the conceptual design phase of a building. It seems so easy however, it take an enormous mind shift for the engineers to become designers. 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. As a result the combined research project Integral Design was started together with the Dutch Building Services society, TVVL, in 2000. As a result of this project a design methodology was developed and implemented in the education curriculum of the Technical University of Eindhoven. In this paper the method and experiences of the application and testing of the method by organizing workshop between professionals and students will be presented
Keywords: Integral Design, Architect, Engineer

1. Introduction.

"*Until the mechanization of building is in service of creative architects and not creative architecture in service of mechanization we will have no great architecture.*" [Frank Lloyd Wright 1953]

People need buildings to protect them against the environmental conditions to be able to work and live in comfortable and healthy indoor air conditions. Architects shaped the built environment since the early beginning of civilization. Building Services make it possible to provide comfort and an acceptable indoor Air Quality for building occupants.

In the last 50 years the world has changed enormously: instead of 3.5 billion there are now living more than 7 billion people on earth with more than 50% in cities with an enormous increased standard of living. However, with 35% of the energy use the built environment is one of the most important areas for sustainable development [RVO 2020]. 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]. There is a need to change the way how architects think about their role in the building design process, we cannot try to solve the problems using the same kind of approach that caused them. Traditionally a designer of HVAC systems was based on known mechanical systems and techniques. This has consequences for the direction in which architecture has to move towards a more sustainable future; a direction in which technology is used to guide architecture. However, there is a gap between technology and architecture and the research as the architect still takes a major leading role in designing both the indoor environment and the energy efficiency of buildings. With the role of the HVAC engineer as a traditional supporting role of the other consulting engineers during the process. The concept, the basic design, is conceived by the architect first, then there is room for other disciplines. However, 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]. To fulfil the demand for Zero Energy Buildings there is a urgent need for synergy between the architectural and engineering domain.

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, team work is key therefor it is necessary to create a place for the needed innovation. The benefits of integrated design are: better decisions, higher speed of response, improved ability to iterate and thus reduce the complexity. Early engagement is essential within building design teams. In line with these developments in practice building design education has moved towards a collaborative practice where designers work in teams [Kiernan et al 2017] and with other disciplines to solve the unstructured problems of design [Kiernan et al 2019]. 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.

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.

In section 2, details of the developed methodology is described. In session 3 the different interventions are 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 followed with a discussion of the results in section 6. Finally in 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 up-dated overview of earlier published papers [Zeiler 2016-2020] and represents the result of research on Integral design that started in 1999 up to now.

2. Methodology

"*You never change things by fighting the existing reality. To change something build a new model that makes the existing model obsolete*." [Buckminster Fuller]

Design problems are wicked as the information to start with is often very limited and there may be many ways of solving them [Kiernan et al 2017]. This poses difficulties for design teams and highlights the requirement to reach consensus on a variety of matters. Arriving at consensus can be challenging for teams and is affected by cognitive diversity [Kiernan et al 2017]. Due to problems resulting from the lack of quality of products and projects, in the early 1960's researchers and practitioners began to investigate new design methods as a way to improve the outcome of design processes [Cross 2007]. Since then, there has been a period of expansion through the 1990's right up to the present day [Le Masson et al 2012, Atkinson & Oppenheimer 2016]. Moreover, many of the design methodologies were developed at universities, and are rarely applied in industrial applications [Dorst 2016].

In 1999, the professional Dutch organization for architects and consulting engineers together with the University of Technology Delft and the Building Services Society started a research to develop an Integral design method to improve the conceptual building design process. Since 2003 this research has continued at the University of Technology Eindhoven and led to a design method based on intensive use of morphological charts [van den Kroonenberg 1988] and its outcome was evaluated in a situation as close as possible to practice amongst professionals, see section 3. The design method has a distinctive feature, the step pattern of activities (generating, synthesizing, selecting and shaping, that occurs within the design process, see Fig. 1.

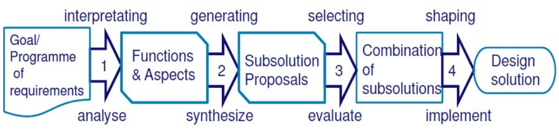
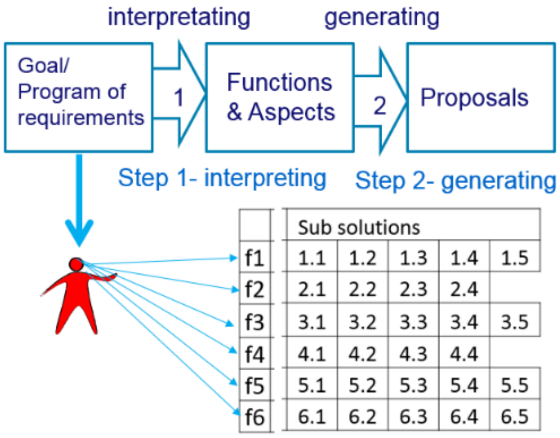


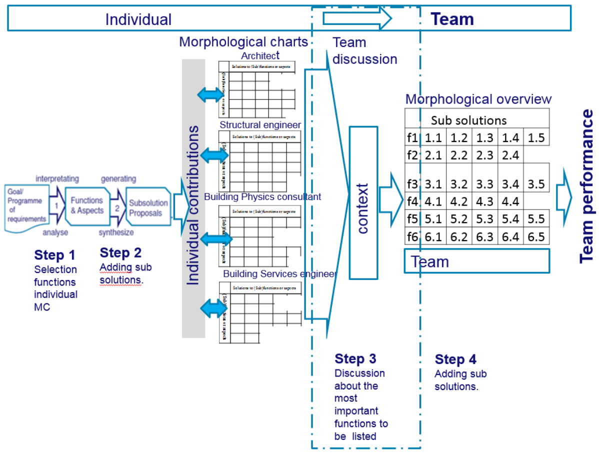
Fig. 1 - The four-step pattern of Integral Design.

A morphological chart is a kind of matrix with columns and rows which contain the aspects and functions to be fulfilled, see Fig. 2 step 1 and the possible solutions connected to them, see Fig. 2 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]. Morphological chart structures the solution space and encourage creativity. Morphological charts are essentially tools for information processing, it is not confined to technical problems but can also be used in the development of management systems and in other fields [Pahl et al 2006].
The use of the morphological charts and morphological overview is an excellent way to improve the design process communication procedure. It makes it possible to record information about the solutions for the relevant functions and aids the cognitive process of understanding, sharing and collaboration [Ritchey 2010, Zeiler 2017].



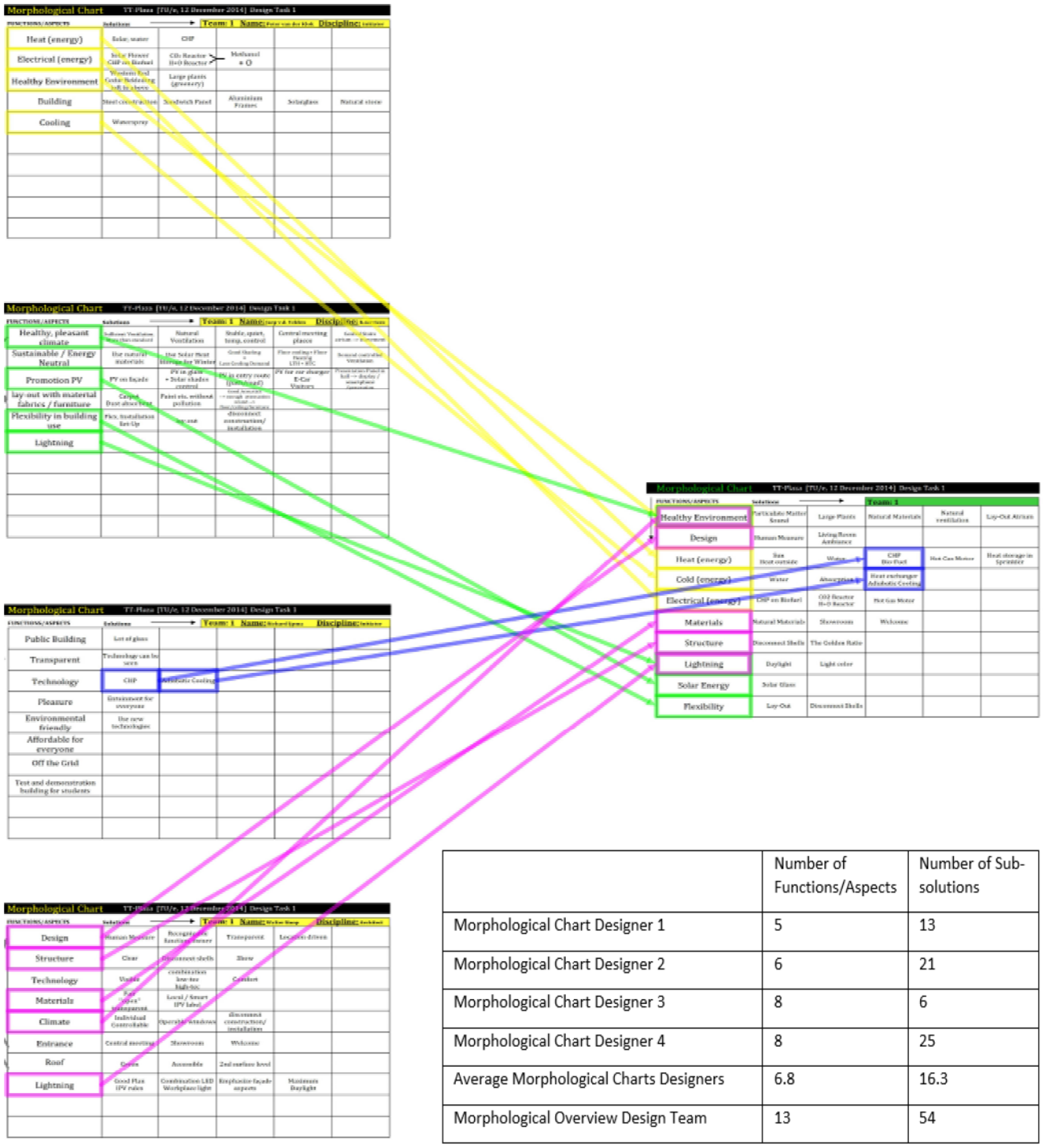
In the first step of the integral design method, the individual designer has to make a list of what he thinks are the most important functions that has to be fulfilled based on the design brief. This is derived from their own specialist perspective. The morphological charts are formed as each designer translates the main goals of the design task, derived from the program of demands, into functions and aspects and is then put into the first column of the morphological chart, see Fig. 3 step 3. 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. Based on the given design task, each design team member perceives reality due to his/her active perception, memory, knowledge, and needs. The morphological charts represent the individual interpretation of reality, leading to active perception, stimulation of memory, activation of knowledge and definition of needs. These individual morphological charts can be combined by the design team to form one morphological overview, see Fig. 3 step 4.
Putting the morphological charts together enables 'the individual perspectives from each discipline to be put on the table', which in turn highlights the implications of design choices for each discipline. This approach supports and stimulates the discussion on and the selection of functions and aspects of importance for the specific design task. Important is the keeping of a phase of individual creativity during the morphological chart.



By structuring design (activities) with morphological overviews as the basis for reflection on the design results, stimulates communication between design team members and helps the understanding within design teams. It stimulates collaboration as it makes it easier to come forward with new design propositions. Through visualizing the contributions morphological overviews stimulate 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 –solution. 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 an example see Fig. 4 [Zeiler 2018].

3. Experiments

Since the year 2000 we, together with the Royal society of architects (BNA), the Association of Consulting Engineers (NLIngenieurs) and the Society of Building Services Engineers, organized a series of workshops in the Netherlands. More than two hundred professionals, with at least 12 years' experience, from different professional organisations 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 organised 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

3.1 Workshops for professionals & students

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. 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. The master project Integral design was initiated by the chair of Building Services in the 2005/06 academic year. 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 [Zeiler 2014]. The frame work of the approach is presented in Fig. 5, the program and setup of the workshop.

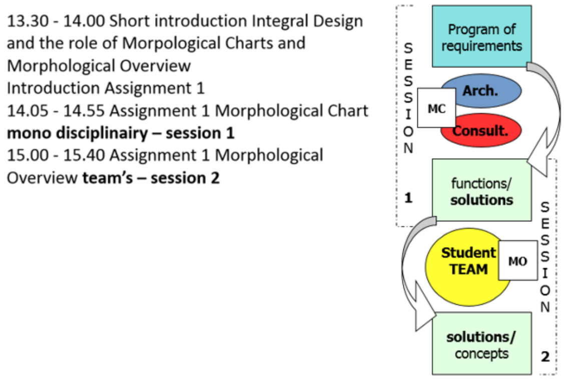


Fig. 5 - Program and set-up of start-up workshop

- Bachelor students (168) 2015-2021

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, age 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, age around 23-25. This was the only mono disciplinary group in the comparison.

- 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 4th 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 to restriction towards the participants, unlike the workshops for professionals in the research of Savanovic [2009] where the participants should have a least 12 years of experience.

4. Results

4.1 From Morphological Chart towards Morphological Overview

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. During all experiments the design teams existed of different disciplines. 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 Fig. 6, 7 and Fig. 8 based on Zeiler [2019] updated.

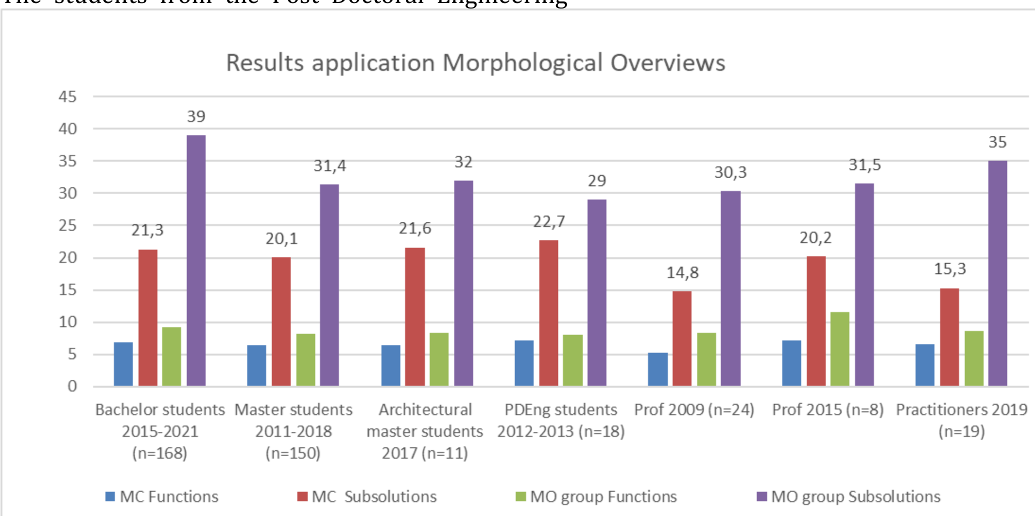


Fig. 6 - The average scores in Morphological Charts & Morphological Overview by individual students, professionals and practitioners for the different groups, based on Zeiler [2019] updated

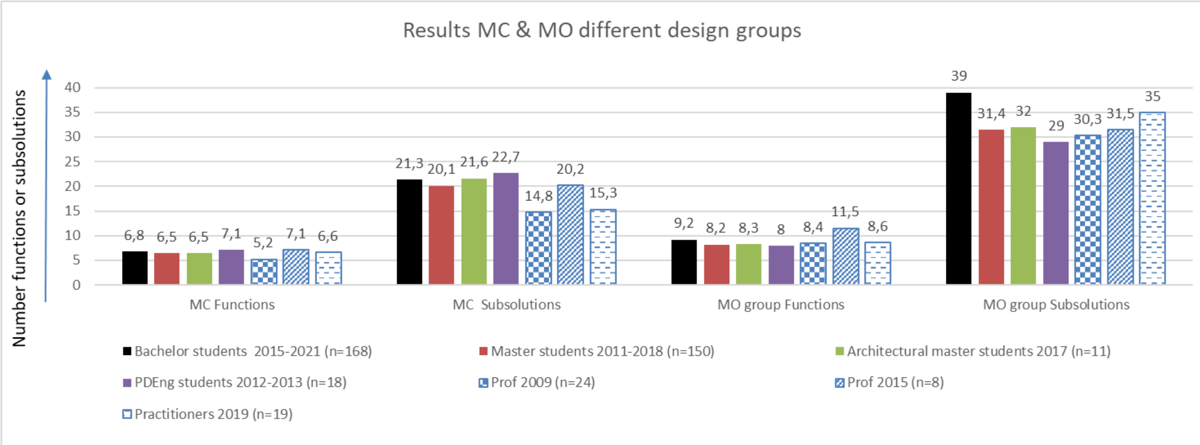
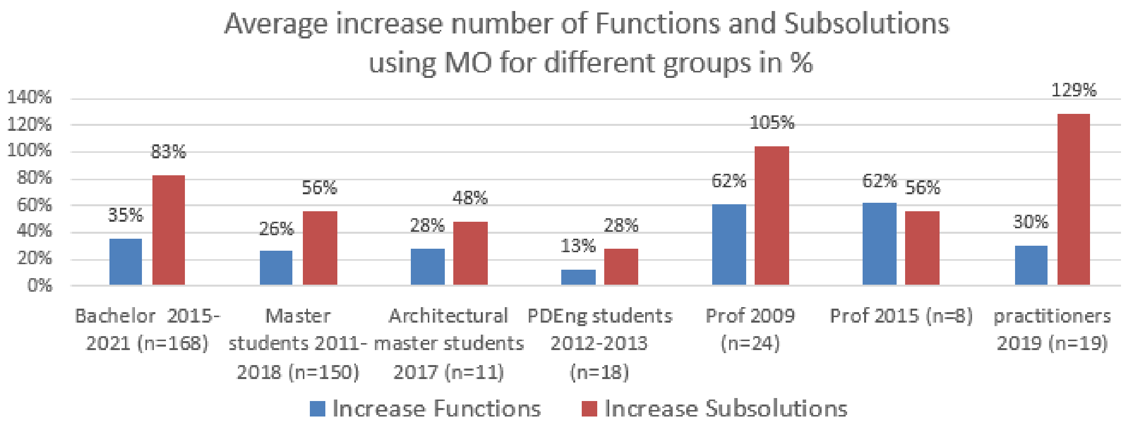


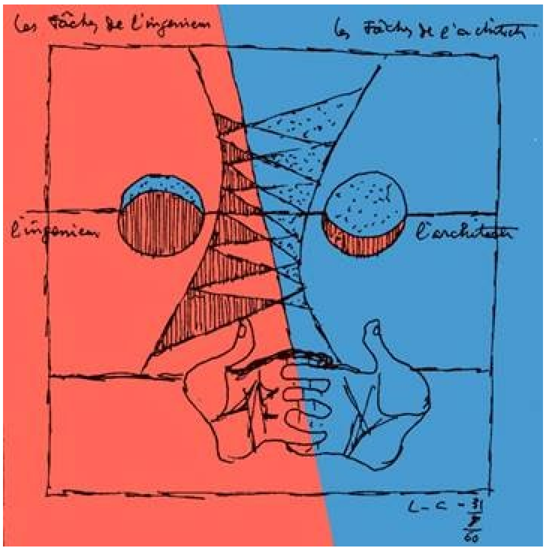
Fig. 7 - Comparison of the average scores in Morphological Charts & Morphological Overview by individual students, professionals and practitioners, based on Zeiler [2019] updated



Using morphological charts during a conceptual design phase is not new, but adding the morphological overview after a team discussion makes it a new innovative team design approach. 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 to the conclusion that it really helps to integrate the different design disciplines and create synergy..

6. Discussion

"*Under the symbolic composition I have placed two clasped hands, the fingers enlaced horizontally, demonstrating the friendly solidarity of both architect and engineer engaged, on the same level, in building the civilization of the machine age*"



[Le Corbusier, 1960, Science et Vie].

The workshop setting of a design team in the conceptual phase of design is getting a more common situation in Dutch building design practice. Schön (1987) has proposed a practicum as a means to 'test' design(ing). A practicum can assess a design method and the degree to which it fits human cognitive and psychological attributes (Frey and Dym 2006). A workshop can be seen as a specific kind of practicum. It is a self-evident way of working for designers that occurs both in practice as during their education. As such a workshop provides a suitable environment for testing and validating the added value of the design approach. Workshops make it possible to gather a large number of students and professionals in a relatively short time, repetition of the same assignment and comparison of different design teams and their results.

There is discussion whether the morphological approach is significantly subjective however, each design team member brings forward their own interpretation of the most important aspects of the design brief and discuss about it as a team. This team discussion leads to the agreed morphological overview which makes the design process transparent. It gives also clients and project managers a possibility to react on specific contributions of architects and engineers and there makes it significantly objective.

7. Conclusions

"*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]

Integral design is a necessity for nature assisted Air-conditioning where architect and consulting engineers have to truly collaborate in the conceptual phase of building design process. What is needed is an optimal exchange of interpretations of the design brief as well as an exchange of ideas on possible solutions, see Fig. 9.

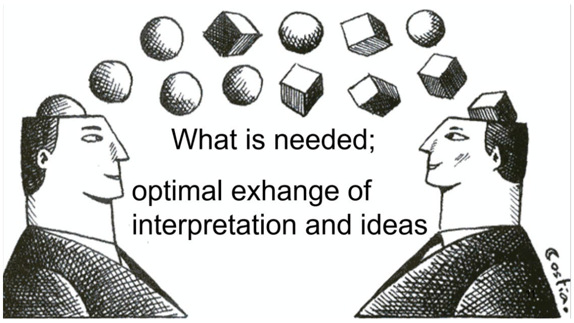


Fig. 9 - The needs with the conceptual design phase

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 and innovative designs, see fig. 10.

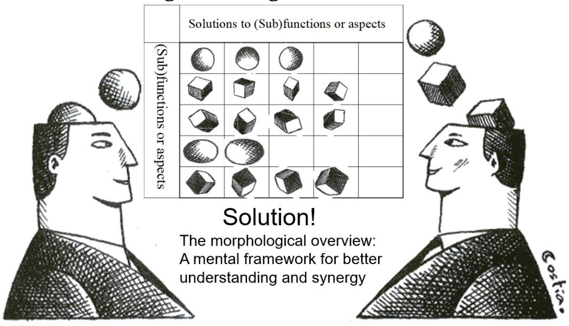


Fig. 10 – The morphological overview to connect the minds of the design team

The main lessons from the 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, who each have new roles in the highly complex tasks of designing sustainable nearly Zero Energy Buildings.
The educational setting allowed us to investigate interventions in the design process of students and professionals. The results were presented and clearly showed the possibilities to stimulate the creativity of design teams by applying the integral design method with its use of morphological overview.

The design method had a major positive effect on the number of proposed sub-solutions and also on the amount 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 was large improved by adding structure to the process. The role of the morphological charts and morphological overview is in structuring the process as well as it enables analysing the conceptual design process in more detail. As such is it a valuable approach to invent the necessary new more sustainable solutions for the future. We see Integral design as a necessity for truly sustainable buildings and as such a prerequisite for the energy transition towards 2050 .

8. Acknowledgement

This research was done in cooperation with the Dutch engineering consulting companies: Deerns, Smits van Burgst, Valstar Simonis, RHDHV and Nieman. The project was financially supported by the professional organisations Techniek Nederland (formerly UNETO-VNI) and Wij Techniek (formerly OTIB] as well as the foundations WOI and PIT. The earlier research which formed the basis was supported by the Dutch Society of Architects BNA, the Dutch Society for Consulting Engineers NL Ingenieurs and the Dutch Society for Building Services Engineers TVVL.

9. References

Atkinson H., Opperheimer M.R., 2016, Design Research – History, theory, practice: histories for future-focussed thinking, Proceedings DRS 2016, Brighton, UK

Bell B. S., Kozolowski S.W.J., 2002. A Typology of Virtual Teams, Implications for Effective Leadership. Group and Organization Managment 27(1), 14-49.

Bont K. de, Zeiler W., Velden J. van der, 2016, Integral Design method to support nZEB design: a real project experiment, Proceedings Clima 2016, Aalborg, Denmark

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

Dorst K., 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

Frey D.D., Dym C.L., 2006, Validation of design methods: lessons from medicine, Research in Engineering Design 17: 45-57

Jackon A., Heywood M., 2019, Development of Integrated Design , CIBSE-ASHRAE Group seminar and webinar, Foster+Partners, London, 18 September 2019

Jonassen, D., Strobel J., and Lee C., Everyday problem solving in engineering: Lessons for engineering educators. Journal of Engineering Education 2006. 95(2): p. 139.

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

Kiernan L., Ledwith A., Lynch R., 2017, How design education can support collaboration in teams, Proceedings E&PDE, Oslo, Norway

Kiernan L., Ledwith A., Lynch R., 2019, Comparing the dialogue of experts and novices in interdisciplinary teams to inform design education, international Journal of Technology and Design Education, published online January 23th 2019, https://doi.org/10.1007/s10798-019-089495-8

King D., 2012, Holistic Approach, CIBSE Journal January 47-49

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., Hatchuel A., Weil B., 2012, How design theories support creativity – an historical perspective, Proceedings 2nd International Conference on Design Creativity, ICDC2012, Glasgow

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

Ölvander J., Lundén B., Gavel H., 2008, A computerized optimization framework for the morphological matrix applied to aircraft conceptual design, Computer Aided Design 41(2): 187-196

Pahl G., Beitz W., Feldhusen J., Grote K.H., 2006, Engineering Design, A Systematic Approach, 3th edition, Ken Wallace K. and Blessing L. translators, Springer

Ritchey T., 2010, Wicked problems Social messes, Decision Support Modelling with Morphological Analysis, Swedish Morphological Society , Stockholm

RVO, 2020, monitor-energiebesparing-gebouwde-omgeving 2019 https://www.rvo.nl/sites/default/files/2021/01/monitor-energiebesparing-gebouwde-omgeving-2019.pdf

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

Schön D. A., 1987, Educating the Reflective Practitioner: Towards a New Design for Teaching and Learning in the Professions, Jossy-Bass, San Francisco.

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/

Wright F.L., 1953, The language of organic architecture, The Magazine of Building, Architectural Forum, May 1953 106-107

Young L., 2014, I cannot think of a better career than services engineering, Interview with Mike Davis, CIBSE Journal April: 29-31

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

Zeiler W., 2017, Design Handbook, A methodical framework, Noordhoff Uitgevers, Groningen, Netherlands

Zeiler W., 2018, Forming design teams for improved performances, Proceedings ASHRAE Annual conference, June 23-27, 2018, Houston, TX,, USA

Zeiler W., 2019, An Integral Design framework for Multi-Disciplinary Design, Proceedings ICED19, International Conference on Engineering Design, 5-8 August 2019, Delft, Netherlands

Zeiler W., 2020, De invloed van de morfologische aanpak op de oplossingsruimte , TVVL magazine 4: 52-57