INTERNATIONAL DESIGN CONFERENCE - DESIGN 2008
Dubrovnik - Croatia, May 19 - 22, 2008.

FLEXIBLE SUSTAINABLE PROCES INNOVATION: INTEGRAL BUILDING DESIGN METHODOLOGY

W. Zeiler and E. Quanjel

Keywords: integral design, sustainability, industry

1. Introduction

Lately the design and the making of the built environment have become more complex. There are presently new and stricter demands connected for comfort, durability and sustainability. In the conceptual design phase, in order to create conditions that assure a built environment that gets better, the ingenuity of the whole design team existing of different disciplines should be used, not only architecture. The quality of the team should be combined with a well considered process of the design itself. Techniques are selected and put together by a team in an integral design process. In addition to the application of proven construction methods, the integral approach demands an attitude of openness and appreciation of the other participating disciplines and their positions.

Traditionally the building to be designed takes a central place in thinking of the design team, see fig. 1A (Hasselt et.al 1998). Looking more closely we find that means and goal are mixed up. More and more the insight is growing that it is not the building to be designed that should be central but the needs of the humans for which the building is intended. This leads to a new approach in which the human needs are key aspects that have to be fulfilled, see fig. 1B.

Problems emanate from a lack of integration between architectural design and design of indoor climate. Building Services consultants have difficulties adapting their methodical and arithmetical way of working to artistic and intuitive characteristics of architectural design. To a slightly lesser degree, the same applies to structural consultants. This notion of 'professional enmity' is not as insurmountable as it may seem (den Hartog 2003).

In the planning of their own new office Kropman, one of the major Dutch mechanical and electrical contractors, wanted to show their design and engineering capabilities. It had to be innovative and so they decided to design an office building with a flexible construction and notable use of sustainable energy. To make this possible, they developed a sustainable IFD (Industrial Flexible Dismountable) building concept. An IFD-building is seen as an expedient for an optimal useable and efficient building process. The IFD-programme was a joined initiative of the Netherlands Ministry of Housing, Spatial Planning and the Environment and the Netherlands Ministry of Economic Affairs. IFD-building is strongly related to ‘Open Building’, based on the ideas of N.J. Habraken (1961). Open building is primarily intended as an organised way of responding to the demands of diversity, adaptability and user involvement in the built environment. In open building the built environment is approached as a constantly changing product engendered by human action, with the central features of the environment resulting from decisions made at various levels.

A central idea in Open Building is to respond to the various needs of individual users through the phasing of the design and implementation process. In order to provide prospective occupants with the opportunity to influence their building, the elements decided by the occupants must be easy to change. Thus adaptability is not merely a means for modifying the dwelling during use; it is first and foremost

a strategy for enabling the fulfilment of individual wishes without compromising. Thinking in levels is the basic Open Building principle.
Open building is an attempt to integrate industrial building and user participation in housing, but the concept can also used for office buildings. It approaches the built environment as a constantly changing product engendered by human activity, with the central features of the environment resulting from decisions made at various levels. The levels which usually are distinguished are the level of city structure, urban tissue, support and infill. Open building entails the idea that the need for change at a lower level such as the dwelling, emerges faster than at upper levels, such as the support. Open building aims at a situation where decisions made on upper levels leave the contents of the decisions to be made al lower levels open.
To meet the challenges of Open building design a methodology has been developed by us. Not only the building to design but also the design process itself became a topic of study. The results of this new approach are called "Duurzaam Flexibele Proces Integration" – sustainable flexible process innovation. The "thinking in levels" approach of Open building was introduced to improve the design and decision process by structuring them at different levels of abstraction. At each level in the design process different decisions have to be taken. One of those decisions is the application of sustainable energy systems and components. However this is rather complex to integrate in the early stages of building design as many aspects have to be taken into account. During the design process participants and their decisions are structured at several levels of decision-making; the infill-level, the support-level and tissue-level. On each level there has to be made a balance between the performance of supply and demand for the building during the life-cycle, see figure 1C.

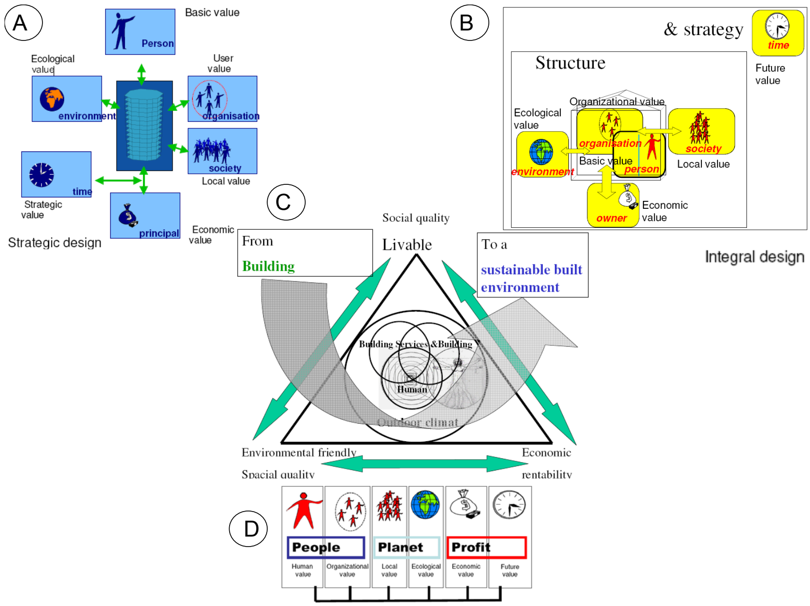

Figure 1. Strategic design (Hasselt et.al. 1998)(A), structure and strategy Integral design (B), the needed balance between different aspects/demands to fulfill within the design process (C) based on the People, Planet and Profit principle

Instead these sustainable energy systems and elements are often added during the final design stages. This results in sub optimal solutions and often leads to complete rejection of proposals to use sustainable energy systems and components at all. At the early design stages, usually only conceptual sketches and schematics are available, often rough and incomplete. Architects tend to develop their designs in a drawing-based, graphical way (prototypes are used to investigate the design concepts). It

is important to mention here that (building) design is a creative process based on iteration: it consists of continuous back-and-forth movements as the designer selects from a pool of available components and control options to synthesize the solution within given constraints.
As the design proceeds, more information and detail will be developed. The main part of the project costs are allocated in the early conceptual phase of product development, still in this phase only few resources (manpower, money) are actually spent on the project (Buur & Andreasen 1989). By the dichotomy of this design process at the early stages of design there is little information, even though nearly all the important decisions have to be made at this time, as fig. 2B by den Hartog (2003) shows. As a mechanical contractor, Kropman, is normally only confronted with the resulting end quality of a design process. Designing their own office gave them the opportunity to approach the design process at a different stage, see figure 2C. As principal of their own office, they used the design process to investigate the influence of introducing knowledge of building services consultants into the early conceptual stages of the design process. Furthermore, even at the requirements stage of the design process the influence of the building services consultant could be effective.

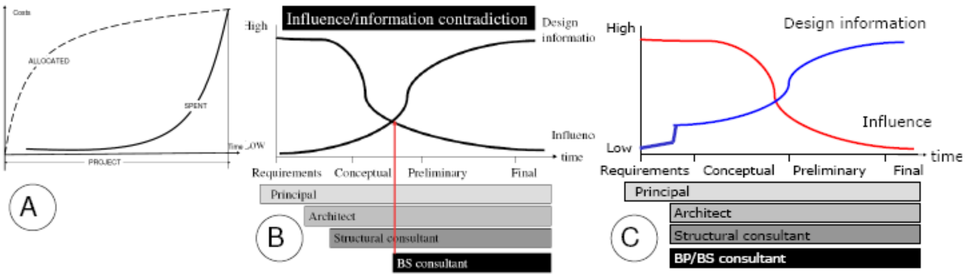

Figure 2. (A) Relation between allocated and actually spent costs during a design project (Buur & Andreasen 1989), (B) Influence / information contradiction at the early stages of design (den Hartog 2003), (C) Influence/ information within the Kropman project

During the process there was a strict focus on implementing sustainable energy solution and their optimal integration with the construction of the building.

2. Integral Design methodology

The idea of the participants was that, by optimising the design process, fewer mistakes will occur and fewer unnecessary costs will arise. The project had to unfold ways to investigate and implement an integral approach for building design. This integral approach encompasses the built environment from initiative to design, construction and real estate management as a seamless whole. This seems to contradict with the subdivision of the construction industry in phases, in which parties operate with opposing interests, resulting in disintegration and waste. The coordination of these independent phases, scales, decision-makings and disciplines are crucial to the creation of a built environment in which the people concerned feel comfortable. This is the core of the integral approach. Integral design is meant to overcome, during design team cooperation, the difficulties raised with the early involvement of consultants. This is achieved by providing methods to communicate the consequences of design steps between the different disciplines on areas such as construction, costs, life cycle and indoor climate at early design stages. The aim is to support all disciplines with information about the tasks and decisions of the other disciplines. Supplying explanation of this information will improve understanding of the combined efforts (den Hartog 2003).
To develop our required model of design support, an existing model from the mechanical engineering domain was extended: Methodical Design by van den Kroonenberg (1978). During early 1970s a prescriptive design model was developed in the Netherlands to teach design to mechanical engineering students at the University of Twente. Called the methodical design model, it was based on the combination of the German (Kesselring, Hansen, Roth, Rodenacker, Pahl and Beitz) and the Anglo-

American design schools (Asimov, Matousek, Krick).
This in the Netherlands familiar model was extended into an integral design model by us because; “it is one of the few models that explicitly distinguishes between stages and activities, and the only model that emphasis the recurrent execution of the process on every level of complexity (Blessing 1993, p.1398)”. Especially the horizontal dimension is not strongly represented in other familiar design models and thus tend to be forgotten (Roozenburg and Cross 1991, p. 216); “not so much by its authors (see for instance Pahl and Hubka) but by its users and, above all, its critics, leading to faulty arguments and misinterpresentations of the model .” A distinctive feature of the integral design model is the four-step pattern of activities that occurs on each level of abstraction with the design process that together forms the Integral Design matrix. The major difference between the integral design matrix and other familiar models is the shaping step, in which the design is ‘shaped’ in to a lower level of abstraction.
The design activities sequence in integral design is: define/generate, analyze/synthesize, evaluate/select, and implement/shape. If compared with familiar models e.g. the basic design cycle of Roozenburg and Eekels, 1995 (analysis, synthesis, simulation, evaluation and decision) the difference is in the implementation and shaping of the design into a lower level of abstraction and as such a focus on the connection between the horizontal dimension and the vertical dimension of the design model. The row of the integral design matrix provide the different issues, functions and aspects, to be solved in the design process, based on the process stages distinguished by methodical design (Problem definition, Working principle and Shaping phase) with a new added process stage: the selecting phase. Once completed, the integral design matrix contains a description of the design process for a specific design task. The description is depending on the rationale applied and may not be chronological: the matrix structures the (intermediate) results of the process independently of the sequence in which they were generated (Blessing, 1993, p. 1398). This makes it possible to focus on the selecting phase and to integrate the opinions of others outside the design team more easily. The design process becomes more transparent and this increases the possibility to reach synergy between the different disciplines and/or designers involved in the design process. The focus within the integral design model is on all activities from all design disciplines that are essential to completeness; nothing essential should be lacking.

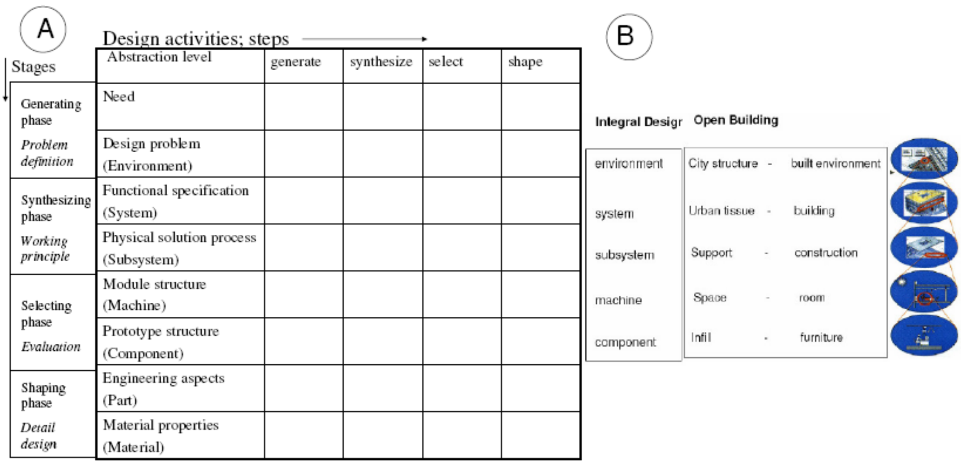

Figure 3. (A)Comparison between system theory and methodical design and (B) Abstraction levels of Open building and Integral Design

The methodical design process can be described at the conceptual level as a chain of activities which starts with an abstract problem and which results in a solution. The original methodical design process is extended from three to four main phases, in which eight levels of functional hierarchical abstraction, stages can be distinguished. A feature of our extended model of Methodical design, Integral Design, is the occurrence of a four-step pattern of activities in each stage. In system theory the same activities are proposed for decision processes as can be found for the design process, see figure 3 A. Within the different phases the main focus is on different steps on a specific abstraction level of the design process. In the matrix stages can be found as well as the four-step pattern of activities. The design process can be looked upon as working one's way through the different levels of abstraction from upper levels to lower levels the design is slowing getting shape. It is possible to connect between the principles of Open building and Integral Design is made see fig.3B.

Besides the framework of the design matrix for structuring the design process there are two distinguished tools which are use within the Integral design method; morphological overviews and the Kesselring method. The use of morphological views makes it possible to structure the systematic combination of design sub problems and solutions; "For the purpose of systematic combinations, the classification scheme to which Zwicky refers as the "morphological matrix" is particularly useful."(Pahl et.al 2007, p.104). The Kesselring method is the basis of the combined technical and economic evaluation technique specified in Guidline VDI 2225 (1977), which essentially originates from Kesselring (Pahl et.al 2007, p.110). Both tools will be briefly discussed in the next paragraph.

3. Tools within Integral Design

3.1 Morphological overviews

For the synthesize activities morphological overviews can be used to generate alternatives in a very transparent and systematic way. General Morphological analysis was developed by Fritz Zwicky in 1947 (Norris 1962) as a method for investigating the totality of relationships contained in multi-dimensional, usually non-quantifiable problem complexes (Ritchey 2002). At first it was thought that the method cold only be used for certain types of problems but subsequently applications have shown that possible use of the method is rule rather than the exception (Norris 1962 p. 115)

Morphology provides a structure to give an overview of the consider functions and their solution alternatives. On the vertical axis of the matrix the required functions or sub-functions are placed. Sometimes also specific aspects will be put on the vertical axis. The purpose of the vertical list is to try to establish those essential functions or aspects that must be incorporated in the product, or that the design has to fulfill. These are often expressed in rather abstract terms of product requirements or functions. Essential is to think of the functions instead of thinking in terms of physical components.

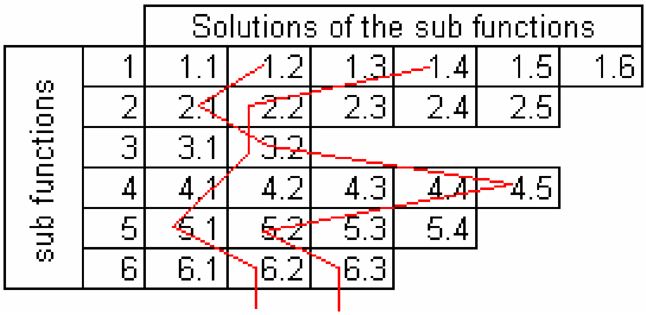

Figure 4. Morphological overview, sub functions on the vertical axis and the possible solutions on the horizontal rows of the matrix, with the lines representing 2 possible solution combinations

The items on the vertical list, the functions, should all be at the same level of abstraction, and they should be independent of each other. They must also cover all the necessary functions of the product to be designed. To make the eventual range of possible solutions not too long, otherwise the number of possible combinations of solutions becomes unmanageable; the list must be comprehended to eight or ten functions. On the horizontal axis possible solutions for these functions or aspects are given.

To keep track of all the generated solutions, the solutions need to be placed in a good overview. By having a good arrangement it is possible to find combinations of solutions that are less likely. For analyzing and evaluating the possible working methods, the solutions of the sub functions can be organized in a morphological overview (fig. 4).

3.2 Evaluation and Decision making; Kesselring decision support

Decision support methods are intended to help designers in making decisions. As people are limited in their capacity to process information, evaluation should be conducted in terms of each criterion separately. Subsequently, the values determined have to be aggregated into a score for the 'overall' value of each alternative. Kesselring developed a visualization technique, with which different variants can be compared with each other.

Within the Kesselring method, the criteria for the requirements are separated into a category for realization and a category for functionality. By doing this the strong point can be seen in the so called S-(Stärke) diagram. To visualize the scores the criteria of the program of requirements are separated in groups with relating requirements. The first group of criteria has to do with the functionality of the design and the other group of criteria with the realization, see figure 5 A and B. Each group of criteria is evaluated and supplementary to the total score of each group of criteria. These criteria are derived from the program of requirements, the design brief.

The total score of the functional and realization criteria is expressed as a percentage of the maximum score to gain. In the diagram the percentage of the criteria for functionality is set out on the y- axis and the percentage of the criteria for realization on the x-axis (figure 5C). The best variants lie near the diagonal and have high scores. It is wise to set values to limit the selection area. A practical suggestion is to divide the area in two with a minimum border set by the x- and y-value of 40 and by (x+y)-value of 55% (figure 5c). The Kesselring method makes singularities visible, whereas that in the normal choice tables and bar diagrams only could be retrieved with much effort. In the Kesselring diagram it is easy to see if the improvements must take place in the functionality or on the realization side.

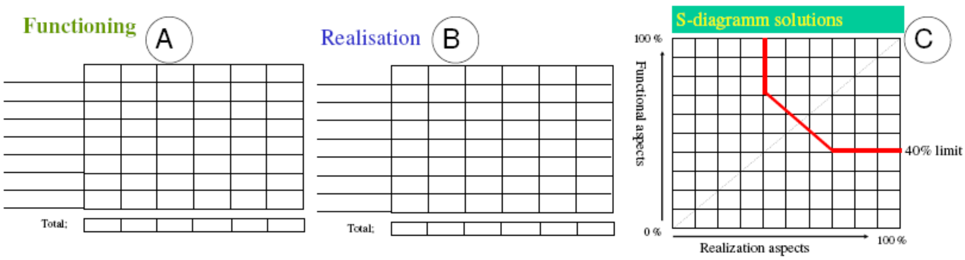

Figure 5. Separation into Functional (A) and Realization aspects (B) and S-diagram of Kesselring (C) showing the evaluated functional and realization aspect of the 4 design proposals of the legenda

4. Results

During the design process of the Kropman building, students of the Technical High School Rijswijk and young high-potential engineers from Kropman worked together on sub-investigations on specific building aspects. Different morphological views were produced for the aspects of reducing the energy consumption of the building and to make in possible to use sustainable energy as much as possible. After completing the morphological overviews different concepts were chosen with the help of the Kesselring method. This showed us that Integral Design with its tools was really supportive during the design process. The studies of the students on specific building aspects, led to new possibilities that were used in the conceptual design phase, resulting in a more fundamental insight into the information flow in the design process.

The application of new innovative construction products and methods in this project demonstrated their potential; and the project reached the status of a demonstration project within the IFD programme of SEV (Stichting Experimentele Volkshuisvesting (Groenedijk et.al. 1999). However, for genuine added value and a further decrease of project risks, further improvement of the early, conceptual stage in the design process is needed.

The conceptual design and the final realization are shown in fig. 6 and fig. 7.

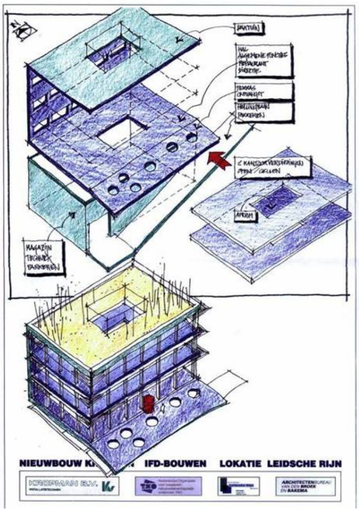

Figure 6. Conceptual design

Figure 7. The final Kropman office

5. Follow-up

Besides designing the Kropman project, one of the design team members was chairman of the steering committee Climate technology of the TVVL (Dutch Society for Building Services). During this period he was asked questions about the investigation of problems concerning comfort and health in buildings. Instead of treating them with an ‘end of pipe solution’ approach, where only the effect is treated and not the cause, the real source of the problems was investigated. These problems resulted from mistakes made during the design process, so it was logical to investigate the design process itself. The parallel between the activities within the Kropman design process and the TVVL activities led to a combined effort. The architect and building services consultant of the Kropman project took the initiative to get in touch with the Royal Institute of Dutch Architects (BNA) and Delft University of Technology (TUD). In year 2000, BNA, TVVL and TUD participated in the research project Integral Design. This project primarily aimed at the reduction of failure costs.

6. Conclusion

To support architects more effectively with their tasks, integral design methodology for conceptual design proves to be helpful. Transforming a design methodology such as the domain-independent design theory of Open building to a specific multi-disciplinary approach helped to construct a bridge between architecture and building services. We think that the proposed Integral Design methodology is a possible solution to bridge the gap between design theory and daily practice.

Acknowledgement

TVVL, BNA and TU Delft have supported the Integral Design project. KCBS, Kropman bv and the foundation “Stichting Promotie Installatietechniek (PIT)” support the new research. References

References

Beitz W., 1985, Systematic Approach to the Design of technical systems and products, VDI 2221 0 Entwürf, VDI, Düsseldorf

Blessing, L.T.M.,1993, A process-based approach to computer supported engineering design, Proceedings International Conference on Engineering design, ICED'93, the Hague, august 17-19, 1993

Buur J., Andreasen M.M., 1989, Design models in mechatronic product development, Design Studies, Vol 10 No 3 July

Groendedijk P., Vollaard, Vos H., IFD-bouwen 1999, SEV Rotterdam january 2000, (dutch)

Habraken, N.J., 1961, De dragers en de mensen, Haarlem(dutch)

Hartog J.P.den, 2003, Designing indoor climate, a thesis on the integration of indoor climate analysis in architectural design, thesis manuscript dated 01/09/2003, Delft University

Hasselt R.L.A. van, Vaan R.P. de, Rutten P.G.S., Trum H.M.G.J., Prestatiegericht ontwerpen en evalueren, reader bij het college "Geintegreerd ontwerpen van gebouw en installaties 7S321, november 1998, TU/e

Kroonenberg H.H. van den, 1978, Methodisch Ontwerpen (WB78/OC-5883), University of Twente, (dutch).

Norris K.W., 1962, The Morphological Approach to Engineering Design, in Conference on design methods, London, September 1962, eds. J.C. Jones and D.G. Thornley, Pergamon Press, 1963

Pahl G., Beitz W., Feldhusen, Grote K.H., 2007, Engineering Design, A Systematic Approach, Third Edition, Translators and Editors Ken Wallace and Luciënne Blessing, Springer-erlag London Limited 2007

Ritchey T., 2002, General Morphological Analysis, A general method for non-quantified modeling, 16th EURO Conference on Operational Analysis, Brussels 1998.

Roozenburg, N.F.M., Cross, N.G. (1991) Models of design process: integrating across the disciplines, Design Studies 12 :215-220

Roozenburg, N.F.M., Eekels, J., 1995, Product Design, Fundamentals and Methods, Wiley, Chichester, UK.

VDI-Richtlinie 2225: Technisch-wirtschaftliches Konstruieren. Düsseldorf: VDI-Verlag 1977

Zwicky F., Wilson A.G. (eds.), 1967, New Methods of Thought and Procedure. Contributions to the Symposium on Methodologies, May 22-24, Pasadena, New York Springer Verlag

Prof.ir. W. Zeiler
Professor Building Services
Technische Universiteit Eindhoven,
Department Architecture, Building and Planning
Vertigo 6.28, Den Dolech 2,
5600 MB Eindhoven, Netherlands
Tel: 00312473714,
Email: w.zeiler@bwk.tue.nl
URL: http://www.tue.nl