Flexible design proces innovation: 
Integral building design method

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Abstract

Sustainable building will be the major guiding principle for renewal of building and spatial planning practice. Design tools for the building services infrastructure are now lacking. New design process structures are needed to make renewable energy solutions on building and infrastructural level more natural and understandable for architect and consultants. A newly developed ontology helps to structure and documents integral building design processes enables design of renewable energy installations on the level of specific abstraction levels. The methodology strongly relates to the Open Building principles.

Keywords: integral design, open building, sustainability, infrastructure
1. Introduction

Global warming, caused largely by CO2 emissions as a result of fossil energy consumption, shows an increasing effect. Climate change is becoming a major problem. As results of Global Warming [Alley 2007] become more and more prominent, it is necessary to look for new possibilities to save energy and to generate sustainable energy to be used for comfort in the built environment.

The energy consumption profile of the Dutch built environment (numbers based on year 2000) shows that in residential buildings 65% of the total primary energy is used for heat, whereas in the non-residential sector electricity is dominant with 52% [Opstelten et al 2007]. It is pointed that although the total primary usage in non-residential sector is lower than that of residential sector, the average energy use per m2 ground floor area is more than double in the non-residential sector, which is due to the larger amount of energy used for building systems (mainly HVAC and lighting). In order to reach an energy-neutral built environment, providing the same level of comfort for the increasing population, new building concepts with a higher (energy) ambition level then currently are needed.

The importance of performance aspects in contemporary built environment, like energy consumption, leads to increased use of active and passive sustainable energy. However, the application of sustainable energy systems and components within current design processes is too complex for integration in the early stages of building design. As a result, sustainable design options are added to the final stages of the design. This results in sub-optimal designs and often rejection of proposals.

Earlier research at Delft University of Technology dealt with the integration of energy saving building components in real-life scenarios [De Wilde et.al 2001]. The results indicate that the most energy saving building components are selected without proper underpinning in the early design phases. By developing an approach for integration of sustainable energy aspects in building design concepts, the actual use of sustainable energy becomes more likely. Integral design, instead of the current practice in which sustainable energy components are added to the building design after the architectural design, is the result.

SBR identified that the most important decisions concerning buildings are made during the early phases of building design [Wichers Hoeth and Fleuren 2001], even though not all relevant information is available then. This hypothetically leads to an influence/information contradiction (Figure 1) during traditional design, where sequential introduction of different disciplines into design process does not support accumulation of information for development of design (as product). The information becomes too late available in the process, when influence on design is limited; e.g. when positive influence on ‘design as product’ often has negative implications on ‘design as process’.
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 [den Hartog 2003]. Therefore a new building design strategy is needed which offers more flexibility.

2. The human perspective of building design

In modern history, design of buildings is seen as largely an individual’s creative act [Habraken 2005, p.28]. This is certainly the case for conceptual design phase, where architect is the one that lays down the vision of the whole building. Moreover, “the belief that a single designer should be in control of all levels of environmental form” [Habraken 2005, p.89] was even seen as a professional ideal in the past. The development of rational methods grew into the Design Methodology movement of 1960’s [Cross 2001], culminating and effectively ending as far as architecture is concerned with the early work of Christopher Alexander. However the need for more rational approaches is strongly felt nowadays by the architectural profession in the last decade.

Recent research in the Netherlands, from within the HVAC sector, for example, has shown the need to better integrate comfort and sustainable energy systems in buildings [Boerstra et al 2006, Opstelten et al 2007]. It is our belief that this can best be achieved by rejecting current design practice, and by organising relevant disciplines into functional, multidisciplinary design teams. In this context, traditional approaches to organize and plan these complex processes may no longer suffice [Van Aken 2005]. This is more understandable when we consider that traditional methods essentially lead to redesign and optimization, whereas to meet the unique challenges in the modern built environment, we need to go further and generate new concepts and knowledge that, it will be argued, will create the structural possibility to arrive at new design solutions.
One clear goal of improving teamwork in building design is the increased possibility to arrive at new building concepts, which may well prove essential in the development of a sustainable built environment. Establishing what sustainability is from an AEC industry point of view provides a point of departure for discussing built environment sustainability and human needs. Traditionally the building to be designed takes a central place in thinking of the design team, see Fig. 2A [Hasselt et.al 1998].

![Diagram showing strategic and integral design approaches]

Figure 2: A. Strategic design, Paul Rutten [Hasselt et.al 1998], B. Integral design with the human needs central

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. 2B.

Due to improvement of the insulation of buildings heating demand is decreasing while more and more electrical apparatus are used in buildings. As a result there is a strongly growing demand for electricity and a decreasing demand for heating. Electricity is traditionally generated in large central plants and distributed throughout the country. During the last decades this has begun to change. More and more decentralized electricity production is achieved by means of wind turbines, combined heat power units and photovoltaic systems. This will change bit by bit the whole distribution system from a strict top down system to a more bottom-up system in which user can supply electricity in to the distribution grid on different levels, see Fig. 3. This means that the user becomes more and more important for the energy planning process and should be included in the energy grid control. The fluctuations of demand from customers as well as possibility for the customer to generate their own electricity through decentralized energy supply, results in unstable process control situations. To stabilize the energy grid the user behavior must be central in both the control and the design process itself.

No longer is it enough to look at only the amount of energy or at exergy level (the quality level of energy). Rather, there is a need to look at the flexibility of the energy source or energy use. This necessity makes designing more complex and unpredictable. Coping with these complex and unpredictable factors requires a more flexible approach in the design process.
An adequate energy infrastructure is essential for comfort and well being in the built environment. Currently, the design of the built environment and the energy infrastructure needed to support it are done by totally different and separated groups of designers. Therefore, there is no shared approach of the design activities on the different levels of scale within the building environment. There is no shared perception (i.e. an ontology) of the design activities which designers perform in the design process of an energy infrastructure on the different levels of scale within the building environment. Without the shared perception it would not be possible to develop adequate design method or approaches for design support that are systematic, consistent, reusable and interoperable. One of the major problems in modeling design knowledge is in finding an appropriate set of concepts to refer to the knowledge, or -in more fashionable terms- finding an ontology. Ontology is generally considered to provide definitions for the vocabulary used to represent knowledge. The ontology role is to reflect a community’s consensus on a useful way to conceptualize a particular domain [Aparrício et al. 2005]. Ontology building deals with modeling a domain of the world with shareable knowledge structures [Geller et.al 2004].

3. Ontology

In the knowledge engineering community, ontology is viewed as a shared conceptualization of a domain which is commonly agreed by all parties. It is defined as ‘a specification of a
conceptualization’ [Gruber 1993]. “Conceptualization’ refers to the understanding of the concepts that can exist or do exist in a specific domain or a community. A representation of the shared knowledge in a specific domain that has been commonly agreed to refers to the ‘specification’ of a conceptualization [ Dillon et al. 2008]. ‘Ontology’ in philosophy means theory of existence in the broadest sense. It tries to explain what is being and how the world is configured by introducing a system of critical categories to account things and their intrinsic relations [Kitamura 2006]. Ontology aims to capture the conceptual structures in a domain by describing facts assumed to be always true by the community of users. Ontology is the agreed understanding of the ‘being’ of knowledge: consensus regarding the interpretation of the concepts and the conceptual understanding of a domain [Dillon et al. 2008] it provides definitions for the vocabulary used to represent knowledge. An ontology aims to capture the conceptual structures in a domain by describing facts assumed to be always true by the community of users. Ontology is the agreed understanding of the ‘being’ of knowledge: consensus regarding the interpretation of the concepts and the conceptual understanding of a domain [Dillon et al. 2008].

Supporting communication between humans for understanding requires less formality than integration of applications. The most complex, and therefore most demanding level of formality would be reasoning (automatically deriving new conclusions from existing knowledge). Therefore, it is necessary to be clear about the purpose of creating a specific ontology because it will determine minimal requirements of the target model [Gruber et al. 2006]. Based on observations from literature, Uschold [1998] identified three main categories of uses for ontology’s (see Figure 4; for further details and examples see Uschold & Gruninger [1996]:

- communication between people. Here, an unambiguous but informal ontology may be sufficient:

- inter-operability among systems achieved by translating between different modeling methods paradigms, languages and software tools; here, the ontology is used as an interchange format (see Figure 4).
Figure 4: Interchange format example. This illustrates the use of ontology as an interchange format to integrate different software tools [Uschold 1998]

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We looked at ontology’s in the built environment for integrating the users. Ontology’s are formal conceptualizations not made l’art pour l’art, but to help to achieve a goal or to perform a task by an actor. In this case, the task involves knowledge-intensive reasoning to understand the world not just static, but to serve practical purposes of action by the actor in his world [Akkermans 2008]: a model to support the process at hand, in our case building design.

4. From ontology to an Integral approach to building design

With the increasing complexity of technical systems a unified principle for science and common ground between a variety of disciplines is needed in the study of complex systems. [Blanchard & Fabrycky 2005]. General systems theory is useful for conceptualizing phenomena such as design, which do not lend themselves to explanation by mechanistic reductionism of classic science. One approach to achieve a supportive, orderly framework is the structuring of a hierarchy of levels of complexity for basic elements in the various fields of inquiry.

Methodical Design makes it possible to link levels of abstraction with the stages and steps in the design process itself [Van den Kroonenberg 1974, de Boer 1989, Blessing 1994, Zeiler 2007]. Stages have been defined as a subdivision of the design process based on the state of the product under development. Dividing a design process into stages is important to structure and decompose the process into easier tasks. The transition between stages provides decision points forcing review and evaluation of the results so far. Stages, therefore, are not only important for efficient progress but also for planning of a project [Roozenburg and Eekels 1995].
A framework of application-independent principles is the basic three-step pattern [generate, synthesize and decide], combined with the 3 different design process phases that can be recognized within the Methodical Design process. When discussing the origin of this step pattern, Van den Kroonenberg refers to the General Systems Theory [de Boer 1989]. The concept of open system in the domain of General System Theory, as it was developed and employed by Ludwig von Bertalanffy [1976], identifies interaction in every aspect of life and also in every aspect of humankind. When essential factors are disregarded, or are not recognized, the operation of the system risks being wrong or sub optimized.

Transforming the program of demands into characteristics for input and output (aspects) and formulation of the different relations between input and output (functions), leads to the construction of a morphological overview. Functions have a very significant role in the design process. Generally, designers think in functions before they are concerned with details. During the design process, and depending on the focus of the designer, functions exist at the different levels of abstraction. An important decomposition is based on functions.

The morphological chart gives an overview of aspect elements or sub-solutions that can be combined together to form overall solutions, see Fig. 6. Morphological charts were first used by Zwicky [Zwicky 1948]. By using morphological charts each discipline can look for all the necessary functions and aspects decomposed from the program of demands. All of the design team members have to come up with their interpretation and possible solutions to the design task. On the vertical axis of the morphological chart the required functions, sub-functions or aspects are recorded. 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 expressed in rather abstract terms of product requirements or functions. On the horizontal axis possible sub-solutions for these functions or aspects are given. The morphological chart gives an overview of aspect elements or sub-solutions that can be combined together to form overall solutions, see Fig. 5 combinations A, B, C and D.
In order to survey solutions, engineers classify them according to various features. This classification provides the means for decomposing complex design tasks into problems of a manageable size. Decomposition is based on building component functions. This functional decomposition is carried out hierarchically so that the structure is partitioned into sets of functional subsystems. Decomposition is carried out until simple building components remain whose design is a relatively easy task. This is like the decomposition which is described in the guidelines 2221 of the “Association of German Engineers”, VDI [Beitz 1985] see Fig. 6.
5. Open building principle

The open building concept developed by Habraken [1961] attempted to integrate industrial building and user participation in housing, but Habraken’s concept can also be used for office buildings. It approached the built environment as a constantly changing product caused by human activity, with the central features of the environment resulting from decisions made at various levels. During the design process participants and their decisions were structured at several levels of decision-making: the infill-level; the support-level; and the tissue-level. On each level, there a balance has to be made between the performances of supply and demand for buildings during the life-cycle. The levels of city structure, urban tissue, support, space and infill were usually distinguished.

Open building entailed the idea that the need for change at a lower level such as the dwelling, emerged faster than at upper levels, such as the support. The “thinking in levels” approach of Open Building was introduced to improve the design and decision making process by structuring them at different levels of abstraction. Different decisions have to be taken at each level in the design process. 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 still have to be taken into account. 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.

To apply the principles of Open Building design to the optimization of the energy infrastructure of a building and the surrounding built environment, a methodology was developed by us. Not only the building to be designed but also the design process itself became a topic of study. The results of this new approach are called “Duurzaam Flexibele Proces Integratie” – sustainable flexible process innovation [Zeiler & Quanjel 2007]. This makes it possible to integrate in a flexible way the energy flows connected to heating, cooling, ventilation, lighting, and power demand, within a building and between buildings and the built environment. This leads to flexibility of energy exchange between different energy requirements and sustainable energy supply on the different levels of abstraction in the built environment.

It is possible to compare the highly abstract approach of Integral Design with the hierarchical abstraction used within Open Building, see Fig.7.
Combining the concept of morphological overviews with hierarchical functional abstraction levels leads to a structure of different sets of morphological overviews for cooling, heating, lighting, power supply and ventilation.

The overviews are used to generate new possibilities for a flexible energy infrastructure in and between buildings to optimize the combination of decentralized power generation, use of sustainable energy sources on the building level and traditional centralized energy supply. The energy flows of heat, cold and electricity have to be optimized together. In Fig. 8 an example of the different abstraction level morphological overviews is presented. In these overviews give the solutions for generation, central distribution, central storage, local distribution, local storage and supply to fulfill the need on the specific abstraction level of built environment, building, floor, room, workplace and person. It represents the orderings principle: abstraction levels, main functions and sub functions.

Figure 7: Comparison hierarchical abstraction Open Building and Integral Design approach.
The function-oriented strategy allows various design complexity levels to be separately discussed and, subsequently, generated (sub) solutions to be transparently presented. This way the interaction with the other participants of the design process is aided, and at the same time design process information exchange is structured, see Fig. 9. It shows an example of the different abstraction levels of morphological overviews are presented. In these overviews the alternative solutions for generation, central distribution, central storage, local distribution, local storage and supply are presented to fulfill the need on the specific abstraction level of built environment, building, floor, room, workplace and person. The overviews are used to generate new possibilities for a flexible energy infrastructure in and between buildings to optimize the combination of decentralized power generation, the use of sustainable energy sources on the building level and traditional centralized energy supply.

The Integral Design morphological approach has several advantages over less structured methods. The morphological chart gives a complete overview of aspect elements or sub-solutions that can be combined together to form a solution. Also, the Integral Design is an excellent way to record information about the solutions for the relevant functions and aspects. It aids in the cognitive process of generating the system-level design solutions and also has definite advantages for communication [Savanovic 2009].
6. Discussion and conclusions

A new design method is defined for a flexible approach to integrate the users’ energy demand and the energy infrastructure within and between buildings. The possibility to combine and exchange different energy flows within the building and between buildings results in a flexible energy infrastructure called Flexergy. The proposed design method is a possible solution for direct design process support for building and energy infrastructure systems for the built environment.

In practice, it is capable of supplying information about sustainable energy applications at a much earlier stage in the design process. Achieving synergy of the environment, sustainable energy sources and the comfort needs of the building’s occupants is the ultimate goal of building design.

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