232: Integral design of sustainable energy into buildings: from synergy to Flexergy

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Abstract
Effects of Global Warming, caused largely by energy consumption, became a major concern during the last decade. Sustainable buildings became the major guiding principle for building and spatial planning practice. Sustainable buildings need an integral approach within the building design process to reach a maximum level of synergy between occupants, building, Heating Ventilation and Air-conditioning (HVAC)-systems and sustainable energy. Design tools for implementing sustainable energy into the energy infrastructure of a building or buildings are presently lacking. In the conceptual phase of design this makes it impossible to balance and tune the demand for and the supply of renewable energy in the built environment in a flexible way. A design methodology for structuring and combining different functions and aspects within a building and between buildings, is presented. This enables the design of new renewable energy concepts aimed on optimizing energy flows and improve comfort for occupants at the same time. This methodology leads to more flexibility of the energy infrastructure; Flex(ible) (en)ergy.

Keywords: integral design, sustainable energy, flexibility

1. Introduction
Lately design and making of the built environment have become more complex. There are presently new and stricter demands connected for comfort, durability and sustainability. Buildings require large amounts of materials and energy. Moreover buildings use during operation enormous amounts of energy and as such is one of the most environmentally unfriendly human activities. Still it is not widely known amongst architects that buildings are responsible for around fifty percent of the total energy consumption [1]. There is a persistent discrepancy between increasing demands for comfort in buildings and the need to decrease the use of energy. Global warming, caused largely by CO2 emissions as a result of energy consumption, shows an increasing effect. Climate change is becoming a major problem. As results of Global Warming [2] 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. Preservation of energy resources, occupant comfort and environmental impact limitation are the key issues of modern and sustainable architecture. A major portion of primary energy consumption, about 40 %, is due to create thermal comfort in buildings by heating, cooling, ventilating and lighting. 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.

2. Methodology
"It all happens in the mind. A place where content outruns form. A place where nothing is impossible" [3]

2.1 Open Building Principle
In modern history, design of buildings is seen as largely an individual's creative act. 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" [4, p.89] is even seen as a professional ideal. In his book 'Palladio's children', where architectural profession is portrayed as singularly obsessed with perfecting form and crafting it down to the last detail, Habraken [4, p.111]. Isolating design as a discrete discipline during the Renaissance opened the path to *innovation*. Habraken [4] explains in his book how, throughout history,

architecture and building (innovation) had always been systematic, in the sense that ways of building rested on shared elements brought together in fixed and familiar ways. Nowadays however, within the building as a composition of systems, the architect is neither the designer of all systems, nor does he or she design with all systems. The most important role of architect is to orchestrate and coordinate the team of co-designers, which is assembled ad hoc for each project. Open building developed by N.J. Habraken [5] attempted to integrate industrial building and user participation. It approached 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. During the design process participants and their decisions were structured at several levels of decision-making; the infill-level, the support-level and tissue-level. The levels of city structure, urban tissue, support, space and infill were usually distinguished, see figure 1. On each level there has to be made a balance between the performance of supply and demand for the building during the life-cycle.

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 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 performances of supply and demand for the building during the life-cycle. 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. Central idea of Open Building was 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.

2.2 A first experiment

To apply Open Building design principles to optimize the energy use and infrastructure of a building, a design methodology was developed by us. 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 [6]. To make this possible, they developed a sustainable IFD (Industrial Flexible Dismountable) building concept. It has been developed with TNO Bouw and the architects Quanjel and van Eck of the architectural office ‘Van den Broek en Bakema’. Also the design process itself was a topic of study. During the design process of the Kropman building, technical students and high-potential engineers did sub-investigations on specific building aspects. Furthermore, TNO Building and Construction Research supported the design-decision-processes. The results of this new approach are called “Duurzaam Flexibele Proces Integration” – sustainable flexible process innovation [7]. A “thinking in levels” approach was introduced in which the design and decision process are improved 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, instead these 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.

2.3 Design Methodology

Researchers have acknowledge the importance of design-assisting tools to help facilitate the integration of sustainability in the building design process especially in the early stages of the building design process when most of the important decisions are made [8]. A key aspect of sustainable architecture is a holistic view of interrelatedness and entirety throughout the building design process {8}. Our integral design 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 sustainable built environment in which the people concerned feel comfortable.

When attempting to integrate sustainable energy aspects into design decision-making, the process must identify opportunities of sustainable energy. Instead of developing new design methods, this research study attempts to utilize existing architectural design characteristics and decision making for the introduction of sustainable energy – resulting in good building designs. This implies defining a methodology that acts as a bridge between architectural elements, such as shapes

and materials on the one hand, and sustainable energy use together with the aspects of indoor climate issues such as overheating and ventilation on the other. To develop our required model of design support, an existing model from the mechanical engineering domain was extended: Methodical Design by van den Kroonenberg [9].
Our Integral 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 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 design, Integral Design, is the occurrence of a four-step pattern of activities in each stage. 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 manageable size. The decomposition is like the "thinking in levels" approach of Open building and it is possible to relate principles of Open building and Integral Design see figure 1.

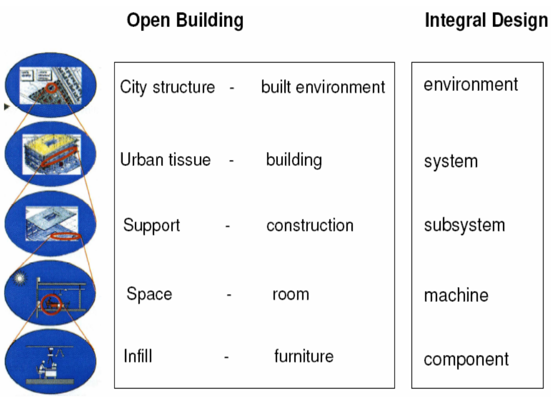

Fig 1. Relation between hierarchical abstraction Open Building and Integral Design approach

2.3 Morphological Overviews

In order to survey solutions, engineers classify solutions based on various features. This classification provides a mean to decompose complex design tasks into manageable problems. An important decomposition is based on functions. Functions have a very significant role in the design process. Functions can be regarded as what a design is supposed to fulfill: the intended behavior of the object. Generally, designers think in functions before they are concerned with details.

Essentially, design is viewed as a black box: 'needs' form the input and 'solutions' constitute the output. The use of a black box is appropriate to determine the functions of the product to be designed. However, as a model of the design process it is hardly useful. In other words: the black box has to be opened, see figure 2.

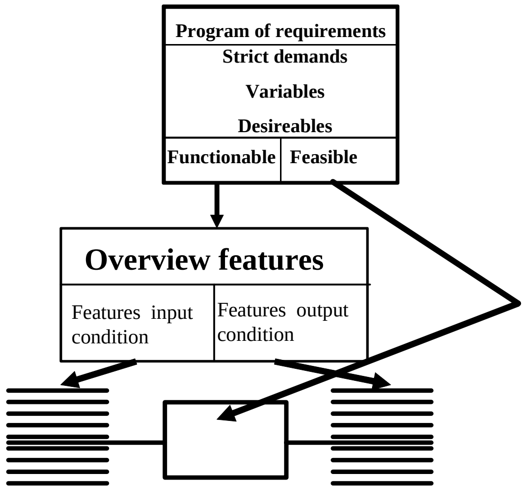

Fig 2. Use of the program of requirements as direct input for the Integral design process

During the design process, and depending on the current focus of the designer, functions exist at the different levels of abstraction. The functional decomposition is carried out hierarchically so that the structure is partitioned into sets of functional subsystems.

For the synthesize activities of the Integral Design process morphological overviews can be used to generate alternatives in a very transparent and systematic way. General Morphological analysis was developed by Fritz Zwicky [10] as a method for investigating the totality of relationships contained in multi-dimensional, usually non-quantifiable problem complexes [11].

During the design process, and depending on the focus of the designer, functions exist at the different levels of abstraction. Morphology provides a structure to give an overview of the functions considered and the alternative solutions. Essentially, general morphological analysis is a method for identifying and investigating the total set of possible relationships or "configurations" contained in a given problem complex.

The main aim of this method is to widen the search area for possible new solutions [12, 13]. Morphology provides a structure to give an overview of the considered functions and aspects and their solution alternatives. Transforming the program of demands into characteristics for input and output (aspects) and formulation of the different relations between input and output (functions) to fulfill, leads to the construction of a morphological overview, see figure 3.

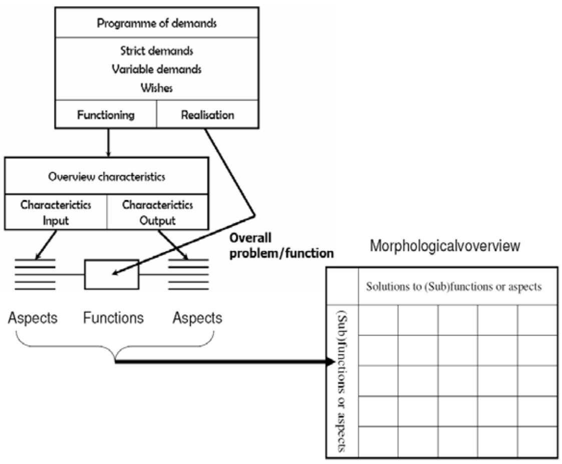

Fig 3. The transformation from the program of demands into a morphological overview

The use of morphological overviews is a key element of the integral design methodology which can improve the effectiveness of the concept generation phase of a building design process [14]. It is this aspect which we focus on in our research. The morphological approach has several advantages over less structured methods. We think it may help to discover new configurations, which thus far may not be so evident and could have been overlooked. The morphological chart gives a complete overview of aspect elements or sub-solutions that can be combined together to form a solution. The purpose of the vertical list is to try to establish those essential aspects and functions that must be incorporated in the product, or that the design has to fulfil. These are often expressed in rather abstract terms of product requirements or functions. Based on definition of functions, morphological overviews make it possible to assess client's needs on higher abstraction levels than what a program of requirements (which is often too detailed) provides.

Also the morphological approach 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 [14]. The morphological approach has several advantages over less structured methods, it may help to discover new configurations, which may not be so evident and could have been overlooked. It also has definite advantages for scientific communication and for group work [11]. We think like Ritchey [11] that the morphological approach has definite advantages for communication and for group work.

2.4 Hierarchical Functional Abstraction Levels

Design takes place in an environment that influences the process and as such it is contextually situated [15,16]. The context of a model of design is composed of a "world view". One of the major problems in modelling design knowledge is in finding an appropriate set of concepts to refer to the knowledge, or -in more fashionable terms- finding an ontology.

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 figure 4.

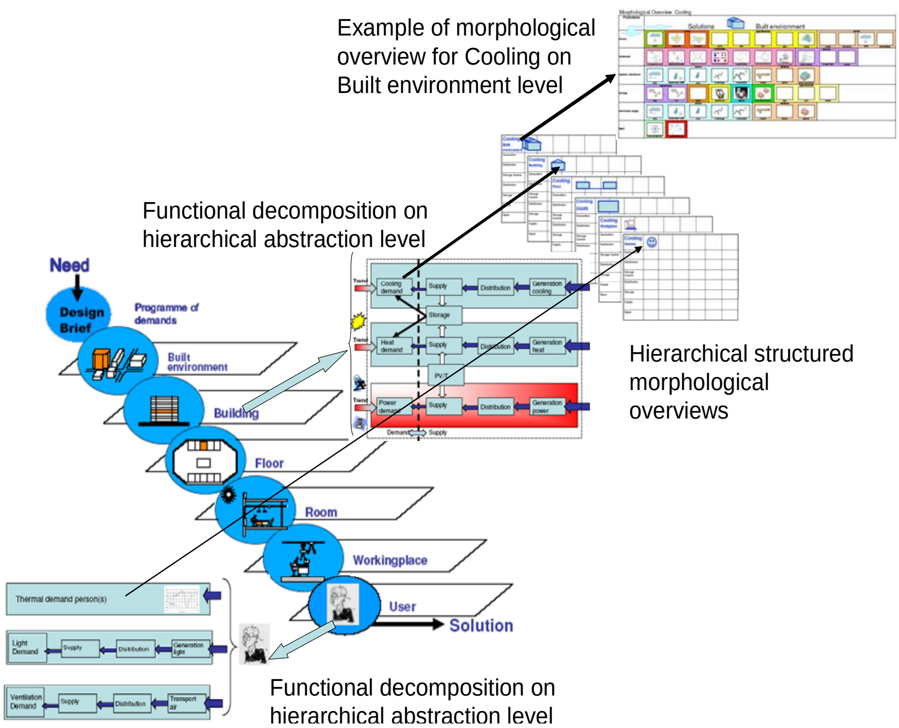

Fig 4. Morphological overviews cooling on hierarchical abstraction of the built environment level

3. Results

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. In figure 6 an example of the different abstraction level 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, use of sustainable energy source on building level and traditional centralized energy supply.

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 source on building level and traditional centralized energy supply. The energy flows of heat, cold and electricity have to be optimized together. For this a new design and control strategy based on Integral design and the use of agent technology is developed. The work on these subjects within the project will continue till 2010.

3.1 Focus on personalized conditioning

One possible major improvement in comfort as well as energy reduction is to focus at the personal environment of the occupants. This means really starting at the level of a person and not as is now common at room level, see figure 5.

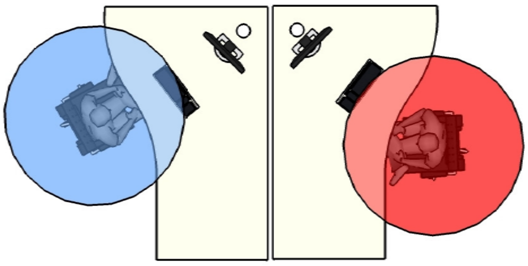

Fig 5. Personalized conditioning concept aimed at the individual occupant [17]

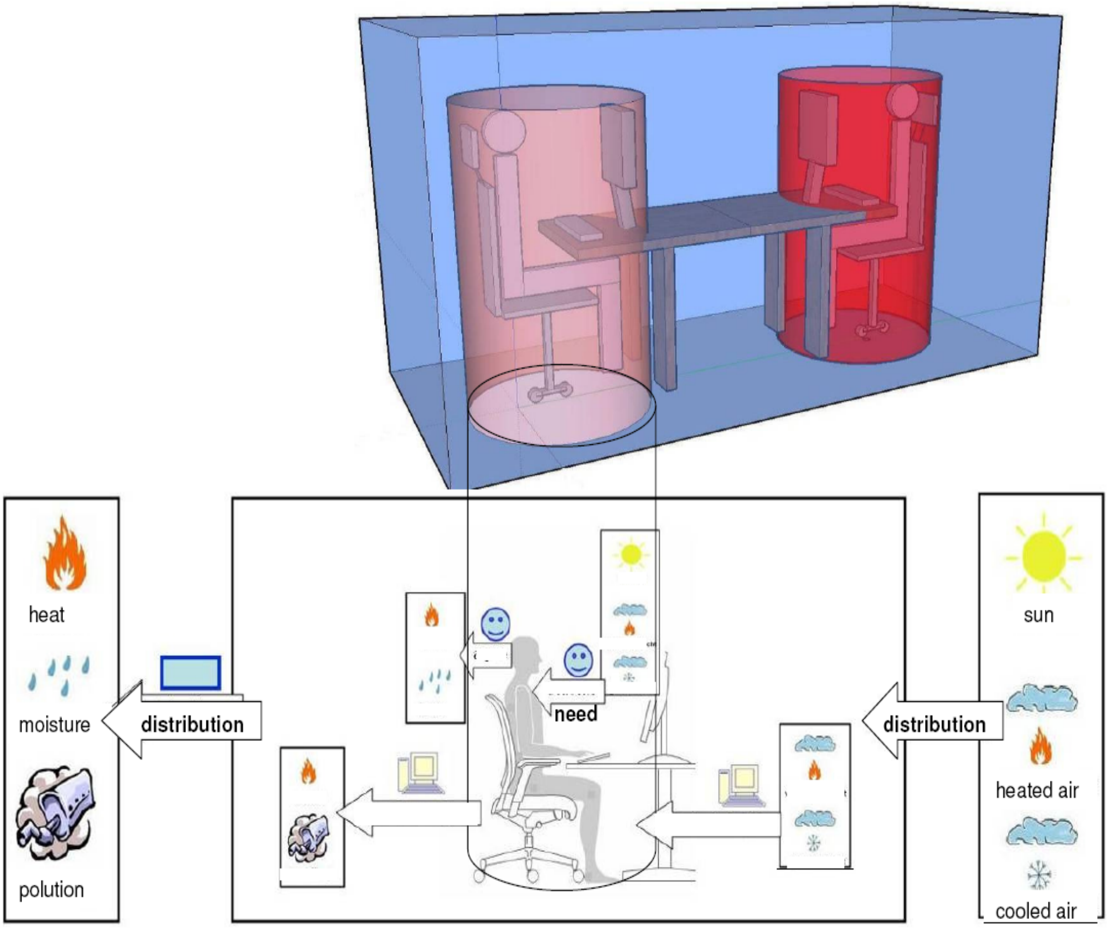

Fig 6. Personalized ventilation concepts with the abstraction layers of workplace and room level [17,18]

This abstract approach leads to new possible concepts which show promise to save energy while at the same time improve personal comfort for the occupants. In our present research we look for instance at using thermoelectrically Peltier heat pump applications for local cooling combined with personal ventilation [17].

4. Conclusion

The paper described research for new energy infrastructural concepts to implement and combine the different energy flows on the level of building and built environment. Central in this approach is the abstract approach to the building design process which makes it possible to generate new solutions for a sustainable energy infrastructure to make buildings comfortable.

Taking the principles of Open Building as starting point, a new integral design methodology is defined for the energy/comfort infrastructure within buildings. In order to allow a stepwise approach in which each design decision has well defined implications, different ontological levels are distinguished based on the Open Building approach. These levels provide a functional structured framework for morphological overviews.

The proposed design methodology is a solution to support the building design process making it possible to implement sustainable energy applications at a much earlier conceptual stage in the building design process. The possibility to combine and exchange different energy flows within buildings results in an flexible energy/comfort infrastructure called Flexergy.

Synergy between environment, its sustainable energy sources and the comfort needs of the building's occupants is the ultimate in a sustainable building strategy, the new concepts which are a result of the used of the described methodology shows promise to reach that goal..

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6. References

1. Melet, E., (2008).*Scarcity creates creativity*, addressed 8 may 2008, http://www.cartage.org.lb/en/themes/arts/Architec/ArchitecturalStructure/GreenArchitecture/Scarcitycreates/Scarcitycreates.htm
2. Alley, R. et.al. (2007). *Climate Change 2007: The Physical Science Basis Summery for Policymakers*, Intergovernmental Panel on Climate Change, Paris, France
3. TiasNimbas. (2008). *If Stephen Hawking can do it, anyone can*, Volkskrant 7 jnue 2008 (Dutch)
4. Habraken, N.J. (2005). *Palladio's children*, Taylor & Francis.
5. Habraken, N.J. (1961). *De dragers en de mensen*, Haarlem (Dutch)
6. Zeiler, W. (1999). *Duurzaam Creatief Ontwerpen*, In: proceedings Dutch Sustainable Energy Conference, 25-26 November 1999, Noordwijkerhout (dutch)
7. Zeiler, W., Quanjel, E.M.C.J. , Brand, G.J.W. van der, 2000, *Duflexpronovatie*, In: Verwarming & Ventilatie, april 2000 (dutch)
8. Trebilcock M., Ford B. and Wilson R. (2006). *Integration of sustainability in the design process of contemporary architectural practice*, Proceedings PLEA, Geneva,
9. Zeiler, W., (2007). *Methodical Design 1972-2006 an historical overview about an integral approach*. Design Principles & Practices: An International Journal 1(1), 59-68
10. 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
11. Ritchey, T. (2002). General Morphological Analysis*, A general method for non-quantified modeling*, 16th EURO Conference on Operational Analysis, Brussels 1998.
12. Cross, N., (1994). *Engineering design methods: strategies for product design*, 2nd.ed., John Wiley & Sons, New York
13. Pahl, G. Beitz, W. Felhusen, J. Grote, K.H. (2006). *Engineering Design, A systematic Approach*, Third Edition, Springer
14. Weber, R.G. and Condoor, S.S. (1998). *Conceptual design using a synergistically compatible morphological matrix*, Proceedings of tne 28th Annual Frontiers in Education, Vol. p171-176
15. Drost, K. and Hendriks, D. (2000). *The Role of the Design Context: In Practice and in the design Methodology*, Proceedings 5th International Design thinking research Symposium "Designing in Contect"' DTRS2000, 18-20 December, Delft
16. Vries, T.J.A. de (1994). *Conceptual design of controlled electro-mechanical systems, a modeling perspective*, PhD thesis Twente university, Enschede, ISBN:90-9006876-7
17. Filippini, G. (2008). *Individual controllable micro climate concepts*, 4 june 2008, (Dutch)
18. Noom, P. (2008). Het individu leidend; Een omgekeerde benadering van het thermisch comfort ten behoeve van de gebruiker, (Dutch) *A turn around approach of the thermal comfort of users: the user leading*, MSc thesis TU Eindhoven