

SYNERGY BETWEEN BUILDING RATING SYSTEMS AND DESIGN METHODOLOGY FOR INTELLIGENT AND GREEN BUILDINGS

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ABSTRACT

There is a strong need for more efficient and more sustainable buildings. At present it is difficult to define the performance of buildings in an objective way to efficiency and sustainability. Goal of this project is to examine and to understand differences between different building rating systems

Considering what makes a good building, results in multiple interpretations based on the different background, training and experiences of the people who answer the question about how good a building is.

What is needed is a new integral design approach which enables to integrate the different aspects of green and intelligent buildings in a supportive framework during the design process. Especially the focus is on Multi Criteria Decision making within the design process and how to support this, so that the decisions about fulfilling 'green' aspects in the design are made transparent for all share holders within the design process.

INTRODUCTION

The current rate of consumption across Europe is unsustainable. We need to reduce our impact - our ecological footprint - by two thirds to a sustainable and globally equitable level. This can only be reached by sustainable design.

Often decision makers assume that sustainable design is mainly about resource conservation - energy, water, and material resources. The last ten years, however, has seen a dramatic broadening of the definition of sustainability to include assurances for mobility and access as affected by land use and transportation, for health and productivity as affected by indoor environmental quality, and for the protection of regional strengths (Loftness et al. 2006).

This broader definition of sustainability is represented in the US by the LEED™ (Leadership in Energy and Environmental Design) standard of the US Green Building Council (Loftness et al. 2006).

The Center for Building Performance and Diagnostics at Carnegie Mellon University likes to expand this definition even further, to give greater

emphasis to contextual and regional design goals, to natural conditioning, and to flexible infrastructures that support change and deconstruction (Loftness et al. 2006). The CBPD defines sustainable design as "a transdisciplinary, collective design process driven to ensure that the built environment achieves greater levels of ecological balance in new and retrofit construction, towards the long term viability and humanization of architecture. Focusing on environmental context, sustainable design merges the natural, minimum resource conditioning solutions of the past (daylight, solar heat and natural ventilation) with the innovative technologies of the present, into an integrated "intelligent" system that supports individual control with expert negotiation for environmental quality and resource consciousness. Sustainable design rediscovers the social, environmental and technical values of pedestrian, mixed-use communities, fully using existing infrastructures, including "main streets" and small town planning principles, and recapturing indoor-outdoor relationships. Sustainable design avoids the further thinning out of land use, and the dislocated placement of buildings and functions caused by single use zoning. Sustainable design introduces benign, non-polluting materials and assemblies with lower embodied and operating energy requirements, and higher durability and recyclability. Finally, sustainable design offers architecture of long term value through 'forgiving' and modifiable building systems, through life-cycle instead of least-cost investments, and through timeless delight and craftsmanship" (Loftness et al. 2005).

The use of sustainable energy will soon be the major guiding principle for building and spatial planning practice. This asks for new sustainable energy infrastructures which need new design approaches. Design tools for the energy infrastructure of the built environment in the conceptual phase of design combined with MCDM methods are presently lacking. Integral Design methodology is meant to help by providing methods to communicate the consequences of design steps on the building level for the energy infrastructure. In particular the use of Morphological Overviews, combined with the

Kesselring method as a decision support tool, will support the early conceptual steps within the design process and make decisions taken during the design process more transparent. The main object of this article is not so much identifying and exhaustively summarizing all MCDM methods usefull for energy planning as a way of examining what to look for in judging the merit of a decision making approach in connection with the design processes within the energy infrastructure of the built environment. This leads to a total building performance thinking which can reduce energy consumption, pollution and waste in existing and new constructions by a factor 4 and simultaneously can improve quality of life within buildings (Hartkopf and Loftness 1999).

There is a strong need for more efficient and more intelligent and green (sustainable) buildings. At present it is difficult to define the performance of buildings in an objective way to efficiency and sustainability.

Goal of this project was to examine and to understand differences between two different building rating systems approaches and to transfer the insights into the conceptual design phase of building design.

SIX S's KEY FACTORS RATING

In November 2003 a project was started, in which students compared 15 Dutch and 15 German modern office buildings. As a result of that former project in November 2004 the 6 best Dutch and German buildings were compared more thorough with each other and it was examined in which extent the Dutch and the German buildings are intelligent (Lony et al. 2006).

The research method is derived from the module "Intelligence Buildings, Key Factors" of the Master of Science Intelligent Buildings of the University of Reading by Clements-Croome (2002). An Intelligent Building is one that provides a productive cost effective environment through the optimisation of four basic elements; systems, structures, services and management and the

interrelationship between them. The module "Intelligence Buildings, Key Factors" describes a method to evaluate the intelligence of commercial offices. Stewart Brand defines six general-purpose sheering layers for analysing the building, called the six S's; Site, Structure, Skin, Services, Space plan and Set (chairs, pictures, appliances) (Brand 1994). The evaluation is based on the six principal aspects of Brand that can be applied to a comparison between buildings. An Intelligent Building is one that provides a productive cost effective environment through the optimisation of six basic elements; site, skin, systems, structures, services, space plan and stuff and the interrelationship between them. Based on these six aspects the comparison is made between state of the art buildings.

After the analysis of the Dutch and German buildings, the results of the buildings will be compared with each other. Every building was evaluated in the same way, whereby the aspects on which there is no or insufficient information will be marked with a neutral score. The following pair of buildings, were compared:

Hoftoren, Den Haag – Post Tower, Bonn

Thermostaete, Bodegraven – Landesvertretung NRW, Berlin

Forum, Amsterdam – Spherion, Düsseldorf

Hoogheemraadschap, Leiden – Energieforum, Berlin

The chart below shows the appreciations of the six S-aspects of the evaluated buildings on a scale from 0 to 100 %. Besides the evaluated two buildings the average of all the 8 evaluated buildings is shown in the graph as a reference. Also the average total score on all the six S-aspects is given. For all the pairs of buildings that are compared a separate chart is made.

The resulting chart of the comparison between Hoftoren and Post Tower shows that the Post Tower is better on almost all aspects. Overall both buildings scores high, but based on the aspects of the six S's the Post Tower is best appreciated, see figure 1.

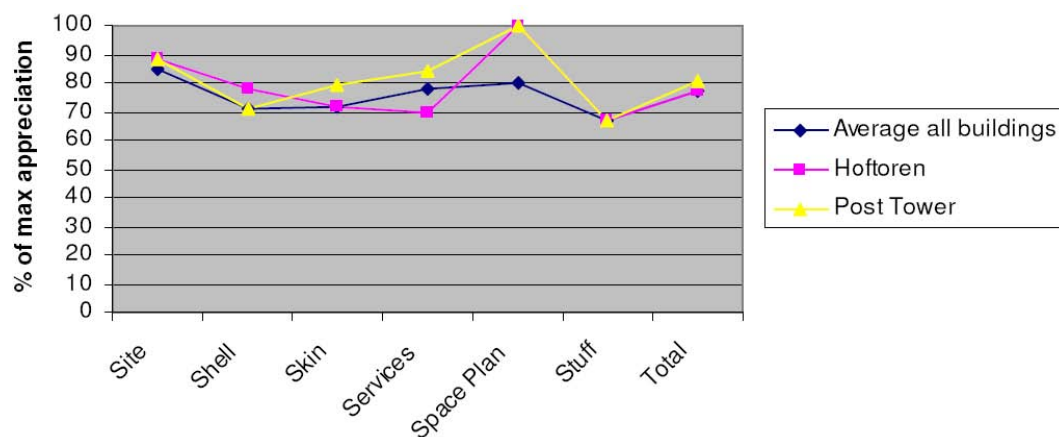


Figure 1. Results comparison buildings by the six-S rating system.

Resume Rating systems

The results of the analysis showed that considering what makes a good building, results in multiple interpretations based on the different background, training and experiences of the people who answer the question about how good a building is. Still far more important the rating systems used for analysis are just making statements about the results of past design process results. We should try to use them for designing. To make this possible the evaluation criteria of the rating systems should be used during the design process. So the key to improvement lies in the connection of the rating systems with the design process itself.

This examination is based on a method to evaluate the intelligence of commercial offices on six principal aspects that can be applied to a comparison between buildings. The article is based on the information what was provided by external parties. Where information needed for the appreciations was not available, the unknown aspects were valued with a neutral score. The available information from lectures, articles, internet, etc. might not always be reliable, but was often the only source of information. The possible appreciations within each of the criteria were determined on basis of mutual deliberation among the project group. All of the appreciations are discussable, but all evaluations were done in a consistent way. The building scores give an idea about the appreciation of the buildings but not in absolute values. The consulting engineers with their own expertise mostly came from the country of the building itself. In most projects the consultants were involved in an early stage of the project. This 'integral design' approach contributes to an innovative building design process.

DESIGN METHODOLOGY

In this section we describe a design methodology, Integral design, to structure the design process and to focus especially on the decision phase of the design process. Within the design method two design tools are essential: Morphological overviews and the Kesselring S-diagram.

Integral Design

Design is a complicated messy process (Hendrickson et al. 2007). Designers are faced with numerous competing requirements and constraints. Achieving environmental goals makes the task more difficult for designers as for most consumers, energy efficiency and recyclability are less important product attributes. This means that designers cannot compromise other product attributes in becoming green (Hendrickson et al.

2007). There is a need for a new integral design approach.

METHODOLOGY

"A theory is exactly like a box of tools"
(Deleuze 1972)

Starting: Methodical design as basis

As stated by Cross, design methodology includes the study of how designers work and think, the establishment of appropriate structures for the design process, the development and application of new design methods, techniques and procedures, and reflection on the nature and extent of design knowledge and its applications to design problems (2001).

In the Netherlands in the early nineteen seventies a methodology was developed to teach design to mechanical engineers at the faculty of Mechanical Engineering of Technical University Twente at Enschede; Methodical Design (MD) model from van den Kroonenberg (1974). Methodical Design is based on the combination of the German design school and the Anglo-American school (van den Kroonenberg and Siers 1992)

This model is exceptional as it is the only model that combines the following characteristics; it is problem oriented and distinguishes, based on functional hierarchy, various abstractions or complexity levels during different design phase activities. Methodical Design makes it possible to link these levels of abstraction with the phases in the design process itself.

Starting from the prescriptive model of Methodical Design, we developed our design process model: Integral Design (ID). In the ID-methodology matrix the cycle (define/analyze, generate/synthesize, evaluate/select, implement/shape) forms an integral part in the sequence of design activities that take place. The ID-methodology matrix provides an overall structure that renders the basic design steps recognizable. The cycle/abstraction matrix represents the recursion of the design steps of a design process cycle from higher abstraction level to lower abstraction level.

By introducing different levels of abstraction the designer can limit the complex design question to smaller sub-questions. The design task can be viewed on each individual level of abstraction. The emphasis at higher levels of abstraction lies on the problem definition phase and generation, while at lower levels of abstraction the emphasis is on developing details of the design product.

Design takes place in an environment that influences the process and as such it is contextually situated (Dorst & Hendriks 2000, de Vries 1994). The context of a model of design is composed of a "world view". The contents of the different views are based on the technical vocabularies in use,

technology-based layers (Alberts 1993). The technology-based layers can be combined with the abstraction levels from the Integral Design methodology. In fig.2 the relation between the technology layers are represented in relation to the conceptual abstraction levels of the built environment according to MD.

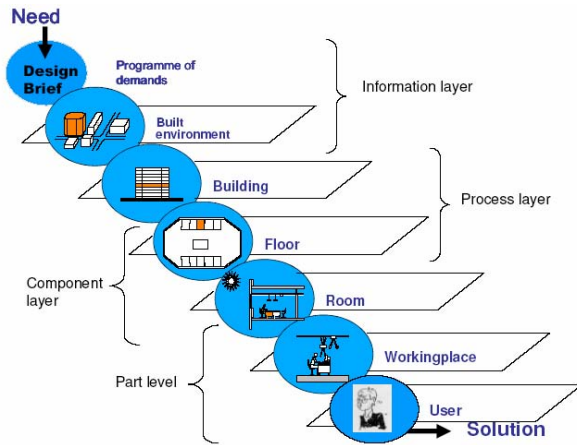


Figure 2. Hierarchical abstraction levels and the technology layer with the built environment

The technology-based abstraction layers can be interpreted as an integral design model. Models are useful because their visualization leads to a reduction of complexity and to improved communication. A model as an abstraction helps the selective examination of certain aspects of the design task. The goal of abstraction is to isolate those aspects that are important and suppress those aspects that are unimportant.

The integral design model developed by us has a distinctive feature of a four-step pattern of activities (generating, synthesizing, selecting and shaping, see figure 3), that occurs on each level of abstraction with the design process, that together form the Integral Design matrix.

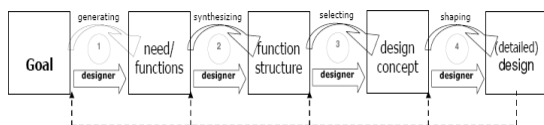


Figure 3. The four-step pattern of Integral Design

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. This makes it possible to focus on the selecting phase and to integrate the opinions of others outside the design team more easily.

Besides the framework of the design matrix for structuring the design process there are two distinguished tools which are used within the Integral design method; morphological overviews

and the VDI 2225 method. Both tools will be briefly discussed in the next paragraph.

Morphological overview

For the synthesizing activities morphological overviews can be used to generate alternatives in a very transparent and systematic way. General Morphological analysis was developed by Fritz Zwicky (1967) as a method for investigating the totality of relationships contained in multi-dimensional, usually non-quantifiable problem complexes (Ritchey 2002).

Morphology provides a structure to give an overview of the considered 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. On the horizontal axis possible solutions for these functions or aspects are given, see (fig. 4).

	Solutions to (Sub)functions or aspects				
(Sub)functions or aspects					

Figure 4. Morphological overview, sub functions on the vertical axis and the possible solutions on the horizontal rows of the matrix.

Combining the concept of morphological overviews with hierarchical abstraction levels leads to a structure of different sets of morphological overviews for cooling, heating, lighting, power supply and ventilation. In figure 4 an example of the different abstraction level morphological overviews is 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.

Morphological connection is an attempt to broaden the space of alternatives, not through problem abstraction, but from different combinations of the problem attributes as in a hierarchy. Despite what the term may imply, this method is not designed for connecting or structuring the different ideas related to a problem to make a decision (Peniwati 2007). Essential within the Morphological Approach is the strict separation between the generation of ‘solution principles’ and choosing between these alternatives: “Utmost detachment from prejudice is the first and foremost requirement of the morphologist (Zwicky 1967)”.

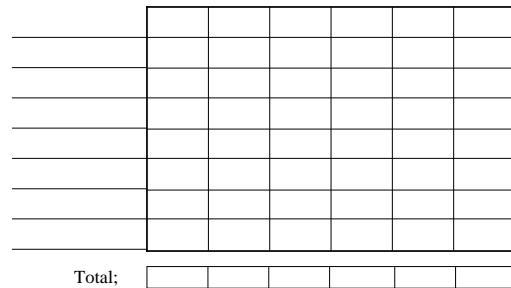
Evaluation and Decision making; VDI 2225 decision support

Nowadays design is conducted more and more in multi disciplinary design teams with a view towards integrating all aspects of the life cycle aspects of a design. This makes decision-making even more complex. Often most of the choices in the design process may be made by intuition and according to simplified decision rules, which is necessary and inevitable (Roozenburg & Eekels 1996). This makes it almost impossible for the different design team members to understand the implicit argumentation of the decisions. Therefore there is a need for formalized discursive methods to structure the decision process and make the process transparent (Derelöv 2004). This would make it easier to share the information and argumentation on which decisions are made within the team.

The most important methods to date are Cost-Benefit Analysis and the combined technical and economical evaluation technique specified in Guidline VDI 2225, which essentially originates from Kesselring (Pahl et al. 2006). 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.

Functioning



Realisation

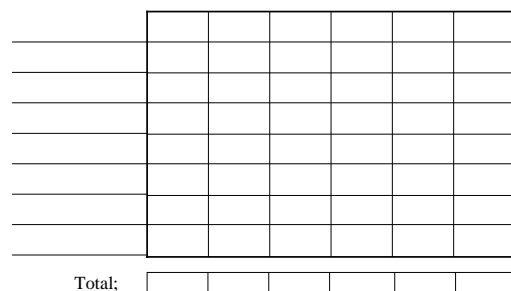


Figure 5. Separation into Functional and Realization aspects

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 6). 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 6). 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.

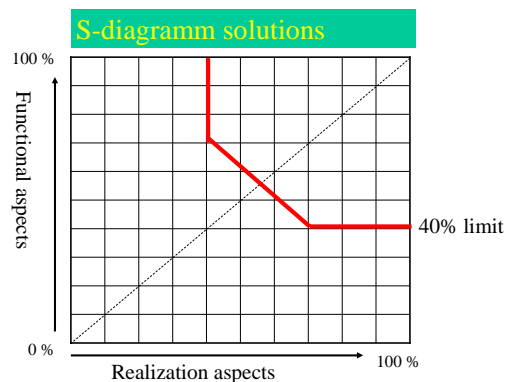


Figure 6. S-diagram of Kesselring showing the evaluated functional and realization aspect of the 4 design proposals of the legenda.

Guideline VDI 2225 (1977) suggest a s-diagram (strength diagram) with the technical rating as the absciss and the economic rating as the ordinate (Pahl et al. 2006). 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. 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. The best variants lie near the diagonal and have high scores. In the VDI 2225 s- diagram it is easy to see if the improvements must take place in the technical or on the economic side. Such diagrams are particularly useful in the appraisal of variants, because they show effects of design decisions very clearly (Pahl et al. 2006).

As an example the study by Verdonshot will be presented as an example of the application of the VDI 2225 method. In the MSc-thesis's at the Technische Universiteit Eindhoven the method is used as a decision support tool during the Integral Façade Design process [2,9,10]. As a starting point of this study four buildings were compared using the VDI 2225 method: The Effenaar, the Kenndy Business Tower, the ABT office and the Bouwhuis, see figure 7.

The evaluation parameters are divided into two groups: functional aspects and aspects with respect to the realisation. The first group contains all aspects concerning the operational period of the façade. The second group contains all aspects that

are not directly related to the user or the operational period, see table 1.

Table 1: List of functional and realisation aspects used in the VDI 2225 method

Functional	Realisation
Energy saving with respect to heating and cooling (compared to single skin façade)	Esthetics
Energy saving with respect to artificial lighting	Capital (initial) cost
View and privacy	Running (operational) cost
Operable windows and/or apertures for ventilation	Maintenance cost
Individual control	Used material
Shading/light level device	Service life
Esthetic life	
Economic life	
Air temperature + radiation temperature (operative temperature)	
Temperature gradient	
Radiation asymmetry (floor temperature)	
Cold radiant surfaces	
Draught (air flow)	
Humidity	
Air quality	
Air quantity	
Daylight	
Glare	
Luminance distribution	
Sound insulation building envelope	
Noise produced by installations/systems	
Surface condensation (temperatuurfactor)	
Interstitial condensation	
Maintenance provisions	

All the results of the measurements in the buildings and all information about the buildings is used to determine the scores of the evaluation criteria. The result is an evaluation of the total performance of the ventilated double facades that are subject of this research compared with a single skin facade. The evaluation criteria are divided in a group concerning the functional aspects and group evaluation criteria about realization aspects. These results are put into the S-diagram, which directly shows the building that has the best balanced performance and which building needs improvement of the functional or realization aspects, see figure 8.

Building	Façade	Ventilation mode	
		Summer	Winter
Bouwhuis office Zoetermeer 	Ventilated double façade 'multi-storey' type 	Outdoor air curtain 	Air supply 
ABT office (Velp) 	Ventilated double window 	Indoor air curtain (reversed flow) 	
Kennedytoren Eindhoven 	Ventilated double façade partitioned by storey (corridor type) 	Outdoor air curtain 	
De Effenaar Eindhoven 	Double glazed single façade 		

Figure 7: Façades and buildings that were compared

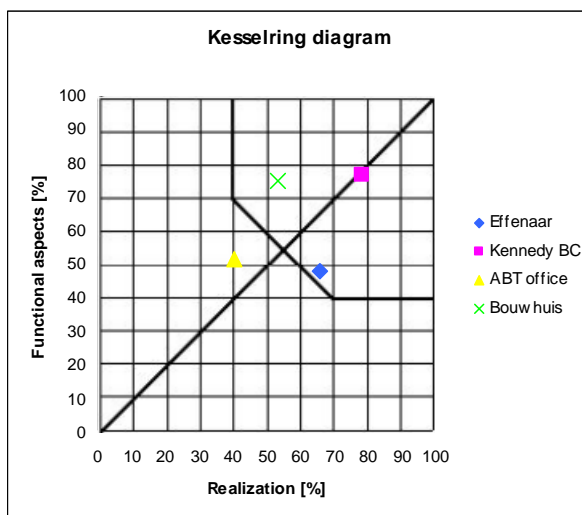


Figure 8: Kesseling diagram of the four building

The façade of the Kennedy Business Centre has the highest and well balanced performance of the four researched façades. The Bouwhuis has a similar score with respect to the functional aspects,

but a much lower score with respect to the realization. Opposite to that, the Effenaar has a much lower score than the Kennedy Business Centre with respect to the functional aspects, but only a little lower with respect to the realization. The ABT office has the lowest score with respect to the realization and a similar score as the Effenaar with respect to the functional aspects.

This evaluation is only valid for these buildings with their façades. In order to look for improvement of the overall performance of the buildings the façades were evaluated according to their type classification. To be able to give possibilities for improvement related to the types of façades, the evaluation is repeated and the possible improvements of the functional aspects and with respect to the realization are analysed for all four façade concepts as such and not related to the specific building. The improvements of the functional aspects of the single skin façade are:

- applying daylight compensation and automatic switching
- adding an operable window to the façade
- improving the control strategy and influence of the occupant
- adding an outdoor shading device
- improving the sound insulation of the façade by using glazing with a higher sound insulation
- applying all necessary maintenance provisions

These improvements result in the following changes with respect to the realization:

- The aesthetic is better due to the air intake and the functionality and impression of space can also be improved for a building with a single skin façade
- The investment costs are much higher. Glazing with a high sound insulation is very expensive and a shading device, operable window and daylight compensation and automatic switching equipment also have to be acquired.

The g-value of the ventilated double façades and window are measured under winter conditions and without the influence of the shading device in the cavity. Measurements in the summer with the shading device down, probably result in lower g-values. The scores for this criterion for the façade types are therefore 1 point higher.

The ventilated double façade partitioned by storey with natural ventilation (outdoor air curtain) can be improved by:

- improving the influence of the occupant
- positioning the shading device near the outside glass layer

The ventilated double window with mechanical ventilation in the reversed air exhaust mode can be improved by:

- applying daylight compensation
- improving the control strategy and influence of the occupant
- increasing the flexibility of the façade
- enlarging the windows, which means more light entering the building
- applying all necessary maintenance provisions

And the ventilated double façade multi-storey type with hybrid ventilation and the possibility of an outdoor air curtain or air supply can be improved by:

- applying a fully glazed inner skin, which increases the flexibility, transparency and sustainability of the façade and improves entering of daylight
- positioning the shading device near the outside glass layer

These adjustments result in the Kesselring diagram of figure 9.

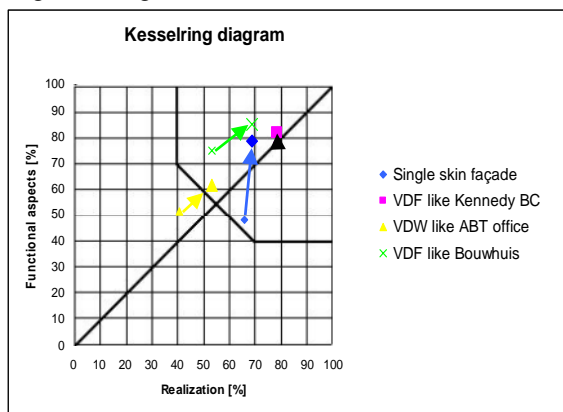


Figure 9: Kesselring diagram of the improved types of façades

This diagram shows that the single skin façade can be improved mainly on functional aspects. The ventilated double window and the ventilated double window multi-storey type can be improved on functional as well as realization aspects. The diagram also shows that there are not many improvements possible for the ventilated double façade partitioned by storey.

Multi-criteria decision-making

Multi-criteria decision-making (MCDM) is a generic term for the use of methods that help people make decisions according to their preferences, in cases characterized by multiple conflicting criteria (Løken 2007). MCDM methods deal with the process of making decisions in the presence of multiple objectives. In most of the cases, different groups of decision-makers are

involved in the process. Each group brings along different criteria and points of view, which must be resolved within a framework of understanding and mutual compromise (Pohekar and Ramachandran 2004). MCDM techniques have two major purposes (Hobbs and Meier 1994);

- to describe trade-offs among different objectives.
- to help participants in the planning process define and articulate their values, apply them rationally and consistently, and document the results.

The object is to inspire confidence in the soundness of the decision without being unnecessarily difficult.

CONCLUSION DECISION MAKING TOOLS AND BUILDING RATING SYSTEMS

Whether using VDI 2225 or MCDA, with all decision support tools the criteria to evaluate the design alternative with should relate strongly with the aspects differentiation of the rating system chosen. So for the 6-S method or the One Planet Living concepts, the aspects to be evaluated can be integrated in the selecting tools within the integral design methodology.

DISCUSSION

The Integral Design aims to support all the disciplines involved in the design process by structuring the process in steps and structuring the information flow about the tasks and decisions of the other disciplines. Supplying explanation of this information will improve team members understanding about each other's tasks and results in combined efforts to further improve the design within the design process. In particular the use of the VDI 2225 method as a decision support tool helps to structure the decision to be taken and make the decision process more transparent and understandable for all the designers from the different disciplines involved in the design process.

At present, MCDA is not that often used for building design (Løken 2007). A more common approach is to apply Cost-Benefit Analysis to a problem. The main principle in Cost-Benefit Analysis is that the performance values for the various criteria are translated into monetary values using commonly agreed-upon conversion factors. The favourable attribute values are summed together as the benefits of the alternative, while the sum of the unfavourable attributes constitutes the cost. The most desirable alternative is the one with the highest net benefit (benefits minus costs) (Løken 2007). Pahl et al. (2006) describe the similarities and difference between Cost-Benefit Analysis and Guideline VDI 2225. The Cost-Benefit Analysis has individual steps which are more highly differentiated and more clear-cut but involve more work than those of Guideline VDI 2225.

Guideline VDI 2225 is more suitable when there are relatively few and roughly equivalent evaluations criteria, which is frequently the case during the conceptual phase of the design process. Also Guideline VDI 2225 is also more suitable for the evaluation of certain form design areas during the embodiment phase of the design process.

Especially the focus is on decision making within the design process and how to support this, so that the decisions about fulfilling 'green' aspects in the design are made transparent for all share holders within the design process. The Integral design approach presents an outline that can be used to support sustainable decision making in multi-stakeholders contexts and would give stakeholders a holistic view that they otherwise may not have (Thabrew et al. 2008).

CONCLUSION AND FURTHER RESEARCH

Integral Design is proposed as a theoretical basis for design of the building, its building services systems and its energy infrastructure. We think that the proposed Integral Design is a support for Multi Criteria Decision Making in conceptual design. In addition to the direct design process support by Integral Design, it will be possible to supply information about sustainable energy applications at a much earlier stage in the design process. And, since this stage precedes the points where most decision-making takes place, these possible sustainable energy applications will have a much better chance of actually being implemented.

The best methods to support the decision step in the design process are the Guideline VDI 2225 and the Cost-Benefit Analysis. Both methods have the possibility to use the criteria of rating systems for evaluation of different design concepts. So the rating system chosen can be incorporated within the design process and support the decision making during the design process itself.

Quality can only be determined by a multi-criteria, multi-disciplinary performance evaluation, which comprises a sum of several satisfaction/behavior functions (Kalay 1999). Synergy between sustainable energy sources, end-user comfort demand and the building energy demand is the ultimate goal. The TU/e (Technische Universiteit Eindhoven) together with Kropman, Installect and ECN (Energy research Centre Netherlands) work on research for user based preference indoor climate control technology. Central in this approach is the user focus of the integral building design process which makes it possible to integrate sustainable energy more easily in the energy infrastructure and reduce energy consumption by tuning demand and supply of the energy needed to fulfill the comfort demand of the occupants building. Taking the user as starting

point a new flexible sustainable energy infrastructure is being defined by using Integral Design methodology; Flex(ible)(en)ergy.

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REFERENCES

- Alberts, L.K. ,1993. YMR: An Ontology for Engineering Design, PhD-thesis, University of Twente, Enschede.
- Brand, S. 1994, How Buildings Learn: What happens after they're built, Viking, New York.
- Clements-Croome T.D.J. 2002. Intelligent Buildings, key factors, MSc Intelligent Buildings, Modul One, University of Reading
- Cross, N. 2001. Designerly Ways of Knowing: Design Discipline Versus Design Science, Design Issues Volume 17, Number 3, 49 - 55
- Deleuze G., 1972, in Intellectuals & Power: A conversation between Michel Foucault and Gilles Deleuze, a transcript of first appeared in English in the book 'Language, Counter-Memory, Practice: selected essays and interviews by Michel Foucault' edited by Donald F. Bouchard. <http://libcom.org/library/intellectuals-power-a-conversation-between-michel-foucault-and-gilles-deleuze>
- Derelöv, M. 2004. On Conceptual Design Reliability, Linköpings University, Thesis No.1121, Licentiat
- Dorst, 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 Context" DTRS2000, 18-20 December, Delft
- Hartkopf, V. and Loftness V. 1999, Global relevance of total building performance, Automation in Construction 8 (1999) 377-393.
- Hendrickson, C., Conway-Schempf, N., Lave, L. and McMichael, F. 2008. Introduction to Green Design, Green Design Initiative, Carnegie Mellon University, Pittsburgh PA, accessed 28 may 2008 www.ce.cmu.edu/GreenDesign/gd/education/gde_dintro.pdf
- Hobbs, B.F. and Meier P.M. 1994. Multicriterion methods for resource planning: an experimental comparison. IEEE Transactions on Power Systems 9(4):1811-7.
- Kalay Y.E. 1999. Performance-based design, Automation in construction 8 (1999) 395-409
- Kroonenburg, H.H. van den, 1974. Methodisch Ontwerpen, De Ingenieur, 21 november 1974, nr.47 (dutch)
- Kroonenburg, H.H. van den and Siers, F.J. 1992. Methodisch ontwerpen, Educaboek BV, Culemborg (dutch).
- Lony, R.J.M., Molenaar, D.J., Rietkerk J., Schuiling, D.J.B.W., Zeiler, W., Brun, M.F. 2006. Comparison between Dutch and German buildings, Proceedings

- VDI Tage der Gebäudetechnik, January 31 – february 1, Leonberg.
- Loftness, V., Hartkopf, V., Gurtekin, B., Hua, Y., Qu, M., Snyder, M., Gu, Y., Yang, X. 2005. "Building Investment Decision Support (BIDS™) —Cost-Benefit Tool to Promote, High Performance Components, Flexible Infrastructures & Systems Integration for Sustainable Commercial Buildings and Productive Organizations," 2005 AIA Pilot Report on University Research, pp. 12-31.
- Loftness, V., Hartkopf, V., Poh, L.K., Snyder, M., Hua, Y., Gu, Y., Choi, J., Yan, X. 2006. Sustainability and Health are Integral Goals for the Built Environment, Proceedings Healthy Buildings 2006, Lisbon, Portugal, June 4-8.
- Løken, E. 2007. Multi-Criteria Planning of Local Energy Systems with Multiple Energy Carriers, PhD Thesis Norwegian University of Science and Technology, Trondheim, April 2007.
- Pahl, G., Beitz, W., Felhusen, J., Grote, K.H. 2006. Translators and Editors Wallace K Blessing L, Engineering Design, A systematic Approach, Third Edition, Springer
- Peniwati, K. 2007. Criteria for evaluating group decision-making methods, Mathematical and Computer Modelling 46; 935–947
- Pohekar, S.D. and Ramachandran, M. 2004. Application of Multi-Criteria Decision Making to Sustainable Energy Planning - a Review", Renewable and Sustainable Energy Reviews, vol. 8 (4), p. 365-381
- Ritchey, T. 2002. General Morphological Analysis, A general method for non-quantified modeling, 16th EURO Conference on Operational Analysis, Brussels 1998.
- Roozenburg, N. and Eekels J. 1995. Product design: Fundamentals and methods, Wiley, Chichester.
- Thabrew, L., Wiek A., Ries, R. 2008. Environmental decision making in multi-stakeholders contexts: applicability of life cycle thinking in development planning and implementation, J Clean Prod (2008), doi:10.1016/j.jclepro.2008.03.008
- VDI-Richtlinie 2225. 1977. Technisch-wirtschaftliches Konstruieren. Düsseldorf:VDI-Verlag
- Verdonschot J.H.A., 2006, Performance of ventilated double facades compared to a single skin façade, MSc thesis Technische Universiteit Eindhoven, June 2006
- 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
- Zwicky, F. and 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