Integral Design Methodology for Collaborative Design of Sustainable Roofs

Emile Quanjel[1], Wim Zeiler[2], Wouter Borsboom[3], Huib Spoorenberg[3]

[1] Technical University of Eindhoven, Faculty of Architecture, Building and Planning, Architect, KCBS, The Netherlands
[2] Technical University of Eindhoven, Faculty of Architecture, Building and Planning, KCBS, The Netherlands
[3] TNO, Building and Infrastructure, KCBS, Delft, The Netherlands

ABSTRACT: Normally the roof is the part of building which gets minimal attention to use for integration with the comfort system of the building. This is striking, as the roof is an important possible building component for containing sustainable energy systems. The sustainable energy possible options are often only considered in a final stage of the design project, when there are almost no possibilities left. Within the 6th framework Pan-European EUR-ACTIVE ROOFer projects aims are development of methodology for supporting new opportunities for increased sustainability. A new integral design methodology to support a collaborative design approach is presented.

Keywords: energy roof, integral design, collaborative design

1. INTRODUCTION

As results of Global Warming become more and more prominent, it is necessary to look for new ways to save more energy and to generate more sustainable energy. [1, 2] In current building practice sustainable energy systems intended for roof application are treated like add-on components to the already completed conceptual building design.

A wide variety of new products, such as photovoltaic (PV) systems and solar collectors, roof lights, ventilation devices and insulation are introduced as adaptable elements related to the roof. Many problems arouse in implementing these products or combinations of products into the total roof, the roofing industry and the integration into the building design. [3, 4] Introduction of a broader variety of products causes a more complex process of designing and engineering, to be organized and developed with more participants with different backgrounds.

These recent developments lead in practice up to a number of sticking points:

- The new products have been seldom developed on the roof to be applied. For this reason there are no uniform standards and building specific performance assess. For this reason frequently own solutions are developed, which have to be adapted on the site itself.

- Another problem is that good products are found oneself installed by not-qualified people. This leads to claims for the impact by leakage caused by rain or snow, but also to wind damage and condensation problems up to significant numbers (to occur).

Within the EU the total amount of failure-costs arouse to approximately 2 billion Euro per year. The secondary damage to the interior of the build environment is at least of same the size order.

The majority of these claims can be prevented if adequate standards and directives for tests and installation existed. European roofers will be faced with a rising number of claims as these problems will not be solved. Although there is specific knowledge, within the roofer industry, concerning how a roof must be made, the roofer should be more active and anticipating on these developments. The added value of this knowledge, should be incorporated on the right moment of the design.

In the concept phase of the building design the most important decisions have to be made in order to optimize the final result. At this stage of the process many of the construction- and user-aspects should be implemented in order to optimize the final building product and to reduce failure costs and damage to the roof and adaptables, during the user phase. (Figure 1)

Surprisingly, there is a scarcity of tools and methods to assist technicians and marketers involved in this phase. Analyzing aspects are necessary to set up the right requirements for such tools. The various activities of the designer are taken as a starting point for this, such as analysis of the demand or the problem, gathering information, generation of possible solutions, transfer of solutions into description of designs, and evaluation and documentation of the design process. [5]

The 6th framework Pan- European EUR-ACTIVE ROOFer project aims at development of a methodology for supporting not only the architect but the whole design team in the early phase of the design process on integrating active roofs – as energy generating integrated building components – in relationship with the product development of the active roof itself.

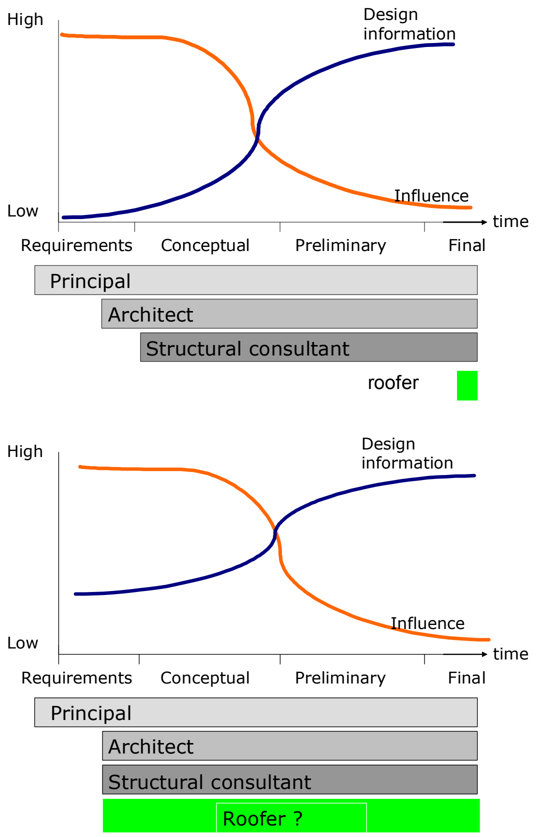


Figure 1: Relationship between Design Information and Influence

2. METHODOLOGY

2.1 Analysis for conditions

Related to the design-process there are many aspects which frustrate a better use of the collaboration between the roofers or roof-industry with clients and architects. First there is a lack of diverse information, language and knowledge. Secondly there are different levels of technical sophistication in the design and building process. Third aspect, if there should be a possibility to innovate: there is a lack of knowledge about innovative roof systems and how to integrate them in the building design. [4,6,7]

Referring to the current situation there is a need for change. The word Active Roof is the concept word related to these changes; the possibility or need to change the culture, process and product related to the roof. Active has in this context several meanings. *Active* roof as an innovative product. This could be in scale of the module (tile), element (prefabricated part), component (total engineered roof) or even the total building. *Active* roof with the described product possibilities means also a more active role in the process. This means other kinds of knowledge, skills, organization and responsibilities. This transformation needs changes, in graduation related to the scale of change, of culture of the roofers, the roof-industry, roof-federations etc.. Change of culture is in fact, in relationship to each other, the simultaneously step by step awareness and transformation of these several aspects. An *active* attitude of the total roof-culture is needed in order to design and construct innovative and better roofs.

A gap exists between theoretical possible solutions and practical application in design practice. Offering design teams and product developers an appropriate methodology will results in decision support. Decision supportive integral design methodology, within design of active roofs, is developed. This implies defining a methodology that acts as a “bridge” between architectural elements such as shapes and material on the one hand, sustainable energy use and the aspects of indoor climate issues such as overheating and ventilation on the other.

Methodical-system arrea

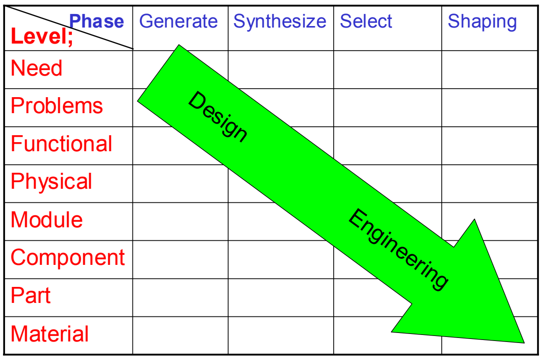


Figure 2: Methodical-system area

2.2 Conditioning the process

In the current situation there are, beside of the more traditional ways by invitation to tender, more sophisticated and specific ways of tendering. At the moment, the organisation of product creation processes is dominated by project teams in the structure of an organisational matrix. This structure has two major negative characteristics. First it does not encourage the speed of product development. Secondly, it requires a lot of co-ordination, which complicates the management of the total design-construction process and often also the management of the use of the product. Stimulating collaboration between separate disciplines is an important goal in developing alternative ways of collaboration within multidisciplinary teams. Successful teams however must have certain key aspects, such as the involvement of the team throughout the complete process or often complete product life cycle. [5]

Collaborative Engineering (CE) is one way of working together in a team with an optimal amount of aspects for success. CE is a temporally form of co-operation in which different organisations closely work together to develop a new product. Main aspect of this co-operation is that these organisations differ in culture, structure, motive for collaboration as well as geographical location. This means that successful collaboration, the activities, processes and tools must be harmonised. Important ways to stimulate harmonisation are:

- agree on the goals that should be reached through collaboration;
- agree on the organisational aspects;
- agree on the allocation of knowledge and experience.

Since in CE is related to complex and intensive processes, it is imperative that extra attention is developed to assure communication – to exchange and share knowledge. [5]

Therefore it becomes more increasingly important to putt all relevant internal and external sources of knowledge and information to good use. A distinction can be made in implicit and explicit knowledge. Explicit knowledge can be specified in a natural language, allowing for a relatively easy transfer to this kind of knowledge. Databases, for instance, can play a helpful role. Implicit knowledge cannot be codified easily. Examples are experience and the applicability of tools to assist in the transfer of this kind of knowledge is small.

As complexity, efficiency and time get more important during design process, the more knowledge is needed to develop the project, the more important the quality of that knowledge is. Management of knowledge is needed, though the tools to support this don't have to be complex. Management of knowledge is primary about people, their specific skills, knowledge and experience. Exchange of knowledge and the way how to optimize it, are essential. [8]

The knowledge exchange / sharing and the decision making process for participants related to the design and construction of the roof is further complicated by increasing requirements on product quality, safety, product sustainability and cost efficiency. Presently most design approaches fail to provide solutions for real collaboration because:
- the information needed is diverse, often in different 'languages', each domain has its own meaning to components and aspects. Adequate decisions require a multidisciplinary approach, involving product and processing know-how, knowledge about logistics, legislation, architect/ customer preferences, etc.
- various members of the design and building process have different levels of technological sophistication.
- the workflow (i.e. the sequence of actions and communications needed for negotiation, collaboration and optimize) underlying the design process is often unclear, which hinders collaboration. [9] (Quanjel, 2003)

The integral approach needed for the development of these knowledge and skills is defined by Quanjel and Zeiler [9] 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 at early design stages. Related to the specific field of the roofer this means the direct connection of construction /user- and design-related knowledge.

To develop our required model of design support and referring to the research of Blessing, an existing model from the mechanical engineering, Methodical Design, is used. [10, 11, 12] The van den Kroonenberg design methodology distinguishes several phases in the design process; problem definition (conceptual and functional design), working principle determination (configuration design) and detail design Methodical design is problem oriented and distinguishes, based on functional hierarchy, various abstractions or complexity levels during different design phase activities. This framework can accommodate the different subjective interpretations of the requirements, inherent to the design team approach. By structuring the requirements the development of the shared understanding is accelerated and the generation of the possible solutions is aided. Through iteration cycle of interpretation-generation steps the set of requirements is continuously refined, and with it also the design solution proposals.[13]

The proposed tool focuses on support rather than automation, and on supporting the whole design process. A primarily problem-oriented, process-based model of design is used. The tool model of design is the morphologic matrix, which acts as the knowledge structure for the team. The model constitutes generic knowledge of a system of a design process, i.e. possible steps; relationships between the steps (based on contents rather than on the sequence of execution); and possible means to support the steps. [13]

2.3 Tools for conditioning primary process phase

There is already research done on how the modelling of knowledge by designers takes place, resulting in 6 main activities.[14] These activities can be classified in two main categories; *battery*- and *increase* processes. A battery process is a process which expires within a determined recipe. An increase process is a process which expires not within a determined process. The relationship between activities and kind of process can be categorize as: [5]

- specification / analysis of question: battery- and increase process
- gain information: battery- and increase process
- generate: increase process – intuition, associate, feeling
- incorporate: battery process
- evaluate: battery process – important to take justified decision
- documentation: battery process – has to be done within procedures

Battery processes can be conditioned with computer-based tools. Most of the innovative activities are increase processes and need tools with more open and flexible characteristics.

Related to the battery processes a database is proposed as tool in order to give more notions in the different aspects of design, sustainable energy, maintenance, safety and construction in relationship with the possibilities for active roofs.

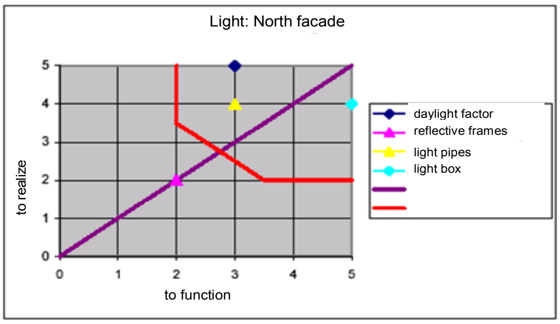
This database structure is set up with specific characteristics:

- Several user possibilities (roofer, industry, contractor, designers and clients);
- Several user aspects (design, sustainable energy, maintenance-safety-assemblage);

- Overview and orientation for existent and future possibilities;
- Easy to work in / easy to complement (new information);
- Easy to deliver / supply to several participants.

To incorporate these programmatic aspects a web-site based structure is proposed. Within this structure there is a very simple first division of aspects; those related to the total building and construction (user aspects) and those related to roof characteristics (roof types, roof materials and roof composition). A maintenance program will be developed to insure the state of the art information will be part of the data-base structure and available for the users.

A second tool, which can both be used into battery- and increase-processes is the Kesselring method. This tool enables the designers to compare different solutions / options / aspects with each other, in relationship with production and functioning. (Figure 3) Selecting the best alternatives leads to introduction of marginal values which limit the choice area. There are limits for the x (functioning) and y (production) and the common value (x+y). The example shows, 35% for functioning and 20% for realisation and 28% as common value. In this case the solution with the light-box is best scoring. The method is valuable to making visible the use- and production phase and how to improve designs.



Kesselring diagram for use of daylight North facade

Figure 3: Example of Kesselring - diagram

In order to support those activities related to the increase processes a more open structure is proposed. To execute the concept generation phase effectively, it is eminent to divide the design task into subtasks or functions and then, to create several solutions to address each function. Once the solutions are conceived, an overall solution is synthesized by identifying individual solutions for each function that are synergistically compatible. Based on this premise, the morphological matrix methodology is extended in this paper by combining it with the theory of coupling. (Figure 4)

Generating concepts from a morphological matrix started some fifty years ago [15] and it is still popular today as an important step in the engineering design process [15, 16]. The morphological matrix represents a methodology for organizing alternative solutions for each function of a system and combining them to generate a great number of solution variants each of which can potentially satisfy the system level design need. The basic format for a morphological matrix is a grid of columns and rows. The first column lists the relevant functions and the row adjacent to each function lists the possible solutions that will achieve the function. In developing the matrix, the designers can use both sketches and text to represent the solutions. Once the matrix is established, the designer must combine the individual solutions into effective conceptual designs. The morphological matrix methodology is an excellent way to record information about the solutions for the relevant functions and aid in the cognitive process of generating the system-level design solution. This methodology is not a replacement for creative thinking but a structured means for developing as well as documenting, design alternatives. It allows the designer to consciously explore design alternatives without confining them to the human short-term memory. [17]

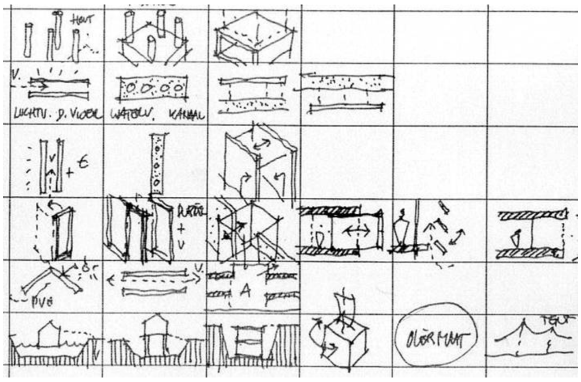


Figure 4: Example of Morphological Matrix

3. RESULTS

3.1 Activities

For constructive implementation / exchange of knowledge within the design process there are 3 main different possibilities:

- reflection in action [18]: which connects the design situation in interaction with a framework for the several disciplines;
- shared knowledge-heterogeneous engineering [19, 20, 21]: a process of aligning cognitive and social-political elements to create and realize a good design;
- ‘bricolage’ [22, 23, 21]: the use of situational resources tendering with resources at hand.

The impact of Donald Schön's work on reflective practice has been significant - with many training and education programmes for teachers and informal educators adopting his core notions both in organizing experiences and in the teaching content. [24]

Although, working with experienced designers from different disciplines is not often done. Mostly the verification of a new methodological concept is done by experiments with student groups [25] or with design groups within one company [14] The relevance is improved by using experienced designers, as there is a major difference in approach between novice and experienced designers. [26, 27]

In the Integral Design project TVVL-BNA-TUD different concepts of workshops have been tested. [9]

Within this ‘learning by doing’ approach newly developed process models are applied, tested and evaluated while professionally qualified designers carry out several design assignments in the repeated series of workshops. There are a number of advantages that the workshops have regarding to standard office situations: the full line-up of design team, avoidance of a ‘laboratory setting’, the possibility to gather a large number of professionals in a relatively short time, repetition of the same assignment and comparison of different design teams and their results. [28]

In relationship to the specific problem of linking knowledge from the construction phase with knowledge of the design phase, an overall model will be chosen in the form of design task workshops. The workshops and case studies will give the possibility to evaluate the outcome of the theoretical model of the supportive process methodology for comfort (HVAC)-system design, engineering and installing in relationship to the roof and the total building. Key aspects of the subject are; generate the knowledge of methodical design, test this process methodology in the context of innovative active roofs and finally train participants to use the methodical design approach and its tools. To that effect, case studies that are complex and innovative enough will be selected, and a series of different type of workshops with experienced professionals from the ONRI (Dutch Association of Consulting Engineers), BNA (Royal Institute of Dutch Architects), IFD (International Federation of Roofing Trades), HHD (Het Hellend Dak) and TNO (Dutch Organisation for Applied Scientific Research) will be organized to investigating the relevance of the approach:

- Case studies of projects in which active roof systems elements were used optimal according to current practice; best projects;
- Workshops, during which architects, climate designers and roofers will work on exercise concerning the conceptual or primarily design of a building and the effects for implementation active roof concepts in comfort systems options.

3.2.Specific results

Monitoring, analysing, comparing and documentation of the several workshops will finally generate a draft for the integral design methodology, that contributes specific issues that should be handled by the methodology or examples of methodologies for similar processes that can be used for inspiration.

Within the total research programme of workshops and the database structure the result will be a concept for active roofs components best practice catalogue. The contributions includes novel active components, cases where active components have been successfully (or unsuccessfully) integrated into roofs, cases that combine components in new ways for added value, or successful roof constructions. Suggestions on how to categorise roofs, active components and active components integrated in roofs.

4. CONCLUSION

By offering design and engineering teams an appropriate, supporting methodology, a collaborative approach becomes more readily supported and thus more likely to be used. Application of new design methodology for active roofs makes system and product development and innovation easier. Strategic objectives addressed the EUR-ACTIVE ROOF-er project will develop and supply tools for European roofers to improve roof quality and reduction of failure cost.

ACKNOWLEDGEMENT

This research is supported by KCBS and the 6th European framework program EUR-ACTIVE ROOFer.

REFERENCES

[1] T. Randall and G. Randall - Bonn Global Warning Earth Summit Fact Sheet - The National Centre for Public Policy Research, Chicago, US, 2001.
[2] E. Fali and D. Simpson - UNEP Annual Report 2004 - Nairobi, Kenia, 2004.
[3] Dr. O. Hohmeyer - Long Term Integration of Renewable Energy Sources into the European Energy System - Lti Research- Business & Economics, Mannheim, Germany, 1998.
[4] EUR-ACTIVE ROOFer - Sixth framework programme-collective research - contract no.:012478, May 2005.
[5] A. Korbijn - Collaborative Engineering – Vernieuwing in productontwikkeling, strategie voor de toekomst – Stichting Toekomstbeeld der Techniek, Den Haag, 1999 (dutch).
[6] De dakensector, structuur en perspectief, Hoofdbedrijfschap Ambachten (HBA), November 1999.
[7] Roofing to 2008: Market Size, Market Share, Market Leaders, Demand Forecast and Sales, Freedonia, Cleveland, USA, January 2005.
[8] M.C.D.P. Weggeman – Kennismanagement, inrichting en besturing van kennisintensieve organisaties – Scriptum, Schiedam, 1997 (dutch).
[9] E.Quanjel, W. Zeiler - Eindrapportage Onderzoek Integraal Ontwerpen, University of Technology Delft (TUD), Delft, May 2003 (dutch).
[10] H.H. van den Kroonenberg, S.J. Siers - Methodisch Ontwerpen - Culemborg: Educaboek, 1992.
[11] S.J. de Boer - Decision methods and techniques in methodical engineering - DPhD thesis, University of Twente (UT), Enschede, 1989.
[12] L.T.M. Blessing - A process-based approach to computer supported engineering design - PhD thesis, University of Twente (UT), Enschede The Netherlands, publ. Cambridge, April 1994.

[13] H. H. van den Kroonenberg - "Methodisch Ontwerpen" - Faculteit der Werkuigbouwkunde, Diktaat Universiteit Twente, University of Twente (UT), 1979.
[14] D.G. Ullman, T.G. Dietterich, L.A. Stauffer – a model of the mechanical design process based on empirical data, Artificial Intelligence for Engineering, Design Analysis and Manifacturing, pp. 35-52, 1988
[15] F. Zwicky - The Morphological Method of Analysis and Construction - Courant Anniversary Volume, New, York Wiley-Interscience, 1948.
[16] V. Hubka, M.M. Andreasen, W.E. Eder, P.Hills - Practical Studies in Systematic Design - Butterworths, 1988.
[17] R.G. Weber, S.S. Condoor – Conceptual design using a synergistically compatible morphological matrix – Frontiers in Education Conference 1998, FIE'98. 28th Annual, Volume 1, p. 171-176
[18] D.A. Schön - The reflective practitioner: how professionals think in action - London, Temle Smith, 1993.
[19] J. Law, - "Technology and heterogeneous engineering; The case of the Portuguese expansion", in: W.E. Bijker et al., The social construction of technical systems; New directions in the sociology and history of technology, MIT Press, Cambridge, 1987, pp. 111-134.
[20] D. Turnbull - "The ad hoc collective work of building gothic cathedrals with templates, string, and geometry"- Science, Technology, & Human Values, Vol. 18(3), 1993,pp. 315-340.
[21] A.D. Rip et al. - Reconstructie van ontwerpprocessen - internal publication, University of Twente, Enschede, 1993.
[22] C. Lévi-Strauss - The savage mind - Weidenfeld and Nicolson, London, 1966.
[23] K.E. Weick, K.E - "Organizational redesign as improvisation", in: G.P. Huber, & W.H. Glick (eds.), Organizational change and redesign; Ideas and insights for improving performance, Oxford University Press, New York, 1993, pp. 346-379.
Werr, A. (1998), "Managing knowledge in management consulting", paper presented at the Academy of Management meeting.
[24] R. Usher - Adult Education and the Postmodern Challenge - London: Routledge, London, 1997.
[25] N.M. Segers - Towards a Data-Structure That Can Handle Ambiguous Information in a Computer-Aided Tool for Early Phase of Architectural Design. In: Proceedings 6th International Conference Design&Decision Support Systems in Architecture, Eindhoven: Eindhoven Universtity of Technology, 2002.
[26] M. Kavakli, J.S. Gero - The structure of concurrent cognitive actions: A case study of novice and expert designers - Design Studies, MIT Press, Cambridge, MA, 2002, pp. 101-124.
[27] M. Kavakli, J.S. Gero J.S - Strategic knowledge differences between expert and novice designers: an experimental study - in U. Lindeman et al (eds), Human Behaviour in Design, Springer Verlag, New York, 2003.
[28] P. Savanović, W. Zeiler, H.M.G.J. Trum, W.A. Borsboom - Integral design methodology in the context of sustainable comfort systems – Design Integration, Eindhoven University of Technology (TU/e) and TNO Built Environment and Geosciences, Eindhoven, 2005.