INTEGRAL DESIGNED DATABASE MORPHOLOGY FOR ACTIVE ROOFS

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ABSTRACT

Roofs can play an important role to make the built environment more sustainable. Therefore design tools were developed to support collaborative design between designers and specialized roof-contractors to create innovative roofs. One of the tools developed is presented: a web-based database. By using a web-based database, a design team is able to store and maintain the existing knowledge and also can add new knowledge about so called active roofs, roofs which generate energy from renewable sources, wind and sun. The concept of the web-based database lay-out and functioning is explained. The results and insights, gained by a workshop with practitioners from the Dutch Construction Industry, are discussed.

Keywords: Collaborative Design, Tools, Knowledge Management, Database.

1 INTRODUCTION

Depletion of energy sources and increasing environmental problems ask for a more sustainable built environment. Sustainable environment can be defined as building for living and working that can be provided in such a way that they meet the needs of the future generations without compromising the ability of future generations to meet their own needs. The roof is an excellent building component to incorporate renewable energy technologies in the way that it already stores many building services components and that it adds value to the roof as architectural and technological part of the total building. Beside of this, the total amount of roof surface which is now mono-functional used is of substantial amount; e.g. in the Netherlands 8% of the total land-surface is occupied by roofs. If supplied with photo voltaic elements, these roofs could produce enough electricity for the Netherlands!

Lack of collaboration in design teams often results in a low mutual level of understanding about the design to produce. Especially the collaboration between designers and contractors is difficult resulting in sub-optimal design solutions and problems in construction. Within the Dutch building industry the roofing industry is aware that better collaboration and knowledge exchange between designers and contractors is strongly needed. In the Dutch Building Industry gaps of knowledge between the worlds of design and engineering are recognized by researchers as well as practitioners (Reymen 2001, van Aken 2005, van Dinten 2006). Knowledge development in daily practice starts with effective collaboration between the participating disciplines in a design team (Nonaka&Takeuchi 1995, Paashuis 1998, Argyris 1999, Emmit & Gorse 2007), making designing the most central activity in new product development (Korbijn 1999, Reymen 2001).

Important for a design process is concept generation; this is a natural habitat for designers for exploring and finding possible product solutions (Lawson 1994). Concept designs can be seen as the basis of knowledge development within the design-team related to specific design solutions (Hatchuel & Weil 2003, van Aken 2005). For that reason concept generation is an essential part of the early design phase. During this phase the most important decisions for the product / product-life-cycle need to be made, even though relevant information and knowledge is lacking and domain experts might not be available (Zeiler et.al. 2005). As a result a lack of innovative designs is observed especially in a specific part of the Dutch building industry; roof design. Professional parties indicate that this lack of innovation most likely is caused by sub-optimal integration of solutions and application in design practice of traditional roof design compared to innovative ‘active‘ roofs. There is a contradiction in influence and design-information between the designer / architect and contractor / roofer, a contradiction in knowledge-flow between disciplines with different educational background (Euractive

Roof-er 2005). Recent developments lead to a number of conflicting aspects in practice related to product-level:

- 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; company specific solutions are developed, which have to be adapted on the site itself;
- Good products are found 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).

At EU level, the total amount of failure-costs sums up to approximately 2 billion Euro per year. Also indirect damages caused by failing roof design concerning the interior of the build environment is at least the same amount of money. In the Euractive Roofer research project, 31 organizations from practice, research and education of 13 different European countries participated. The primary aim of the research project is to structure the information exchange in a design team to support the design of innovative, active roofs. The definition of an Active Roof is that of a roof that has a multifunctional relation to the total building-design and use, related to sustainable energy use; such roofs have to fulfill an active role in generating energy for the total building envelope through the use of sustainable energy. Different concepts for tools for structuring and sharing design knowledge were developed and tested in a hands-on knowledge structuring Collaborative Design setting of workshops; a setting which enables communication within a team of designers (architects) and contractors (roofers), see Fig. 1.

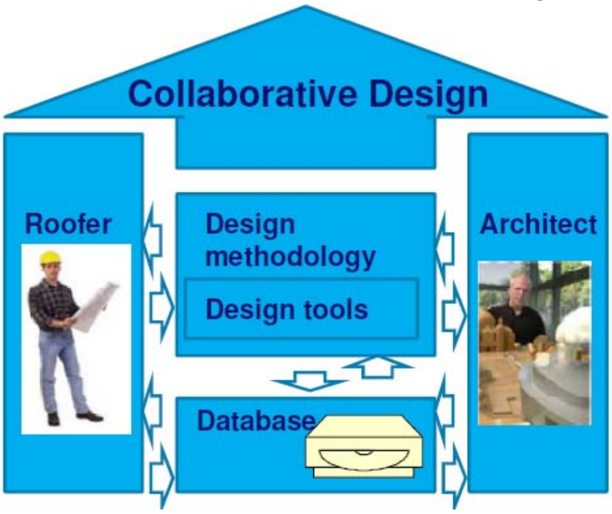

Figure 1. Concept for collaborative design setting between architects and roofers

The other concept concerned a database lay-out that should give both architect and roofer insight in specific object- and realization information and knowledge related to the design of roofs as integral part of the building and its process. The database can be used both in a setting for synchronous as well as a-synchronous communication.

In both concepts the structuring design method of Morphological Charts (Zwicky & Wilson 1967) was used related to explicit used and needed knowledge by the design team. This paper focuses on the background and developing of the database as well as the lay-out of it related to the Integral Design method with its use of Morphological Charts.

2 METHODOLOGY

The integral design approach (Savanovic 2009) of the research methodology means different viewpoints on the same topic. For this research the two main viewpoints are that of the designer – the architect – and the constructors – the roofer. The focus for the Workshop is on the explicit knowledge used by the roofer and architect in the early phase of the design, as most important decisions are made in this phase in relationship to cost and risks during the construction and user phase of a building. Related to the roofer we define this as realization-knowledge and of the architect as design-knowledge, both will also have knowledge of the other ‘field. Important for the usefulness of the workshop is that participants must have enough experience in realized projects. In relationship with knowledge sharing and knowledge development in the early design phase, this means that both roofer and architect have also process-knowledge.

The main questions hereby are which knowledge is used by which participant in relationship with innovative roof-design. Related to the research it was also interested how the professionals experienced two supportive tools of different kind; the Morphological Overview and the Web-based Database Structure. Therefore these two views were two separate parts of the Workshop. Part one with focus on the design and the use of the support tool Morphological Overview. The second part focused on the support tool Database; as parallel knowledge-back up and reflection-tool on the design of part one.

Workshops

First part of the Workshop was split up in an individual part and a part in a team, this to get insight in the functionalities and solutions used by the specific participant of roofer or architect alone and in collaboration. The second part of the Workshop was also individual and in collaboration but then focused on the Database. The third part, as a reflection-part of the Workshop for the participants, the teams had to present there designs to the other participants. Teams were in the same configurations during the Workshop because the focus was for the participants to work on designing innovative roofs in a collaborative setting with different tools.

Type of participants 3 disciplines: architect constructor 1. Architects (9), 2. Constructors/ Builders; Roofers (8),.Facaders (1)		Number 18 persons 9 teams	Arrangement One day, use of MC and Database in relation to Integral Design; development of functionalities and solutions
Days | hours/day 1 | 5	Sessions/day | total 4 | 4	Time/session | total 45 min. | 180 min.	
Observations by Researcher (during) / students (after)	Arrangement 1 General + video	Using Video / Output design-sessions	Additional Photo, questionnaires (before, after + 6 Months)
PROGRAM 1 Introduction Research and Integral Design (30min) 2 1st. Design session individual + MC (30min) MC MC 3 2nd. Design session team + MC (30min) MC Break 4 3rd. Session individual with database (30 min.) 5 4rd. Session team + database design session teams (30 min) 6 Presentation teams, discussion		**AIM** - Which kind of functionalities are used by different disciplines, how are they part of MC and design solutions. - Which kind of functionalities in database are important for different disciplines, how are they part of design solutions. -Influence on former aspects on knowledge sharing between different participants.	

Figure 1. Set-up of the workshop

Three different methods where used for analyzing the Workshop results; the explicit results by the Morphologic Overviews and designs made by the participants and the questionnaires filled in by the participants. The third method was used as feed-back for specific information about the used representation by roofer or architect and process; video-film and photos each 10 minutes. The questionnaire for the session with the Morphological Overview was also used in previous workshops. One video-camera with microphone was used per team.

Morphological charts

General morphological analysis was developed by Fritz Zwicky (Zwicky & Wilson 1967) as a method for identifying and investigating the total set of possible relationships or configurations contained in a given problem complex (Ritchey 2002), while morphological *charts* are listed as one of design methods by Jones (1970): “morphological charts are intended to force divergent thinking and to safeguard against overlooking novel solutions to a design problem” (p.293). The main aim of using Morphological Charts is to widen the search area for possible new solutions. Morphology provides an arrangement for supporting overview of the considered functionalities and aspects and their solution alternatives. Functionalities are all those functions and aspects which are related to the object-, realization- and process-design. Transformation of the program of demands, by the team, into aspects and functionalities, (vertical axis Fig.2) and formulation of the different solutions and relations related to these aspects and functionalities (horizontal axis), leads to the construction of a Morphological Overview (Fig.2). Within the Morphological Chart the vertical rows represent functionalities and aspects related to the design-task, the horizontal rows are solutions for the functionalities or aspects. Example of the use of the Morphological Chart for Adaptable Roof Design: vertical row represents functionalities and aspects such as construction, sustainable energy sources, horizontal row are solutions of the functionalities or aspects; red en green lines give possible combinations for possible solutions.

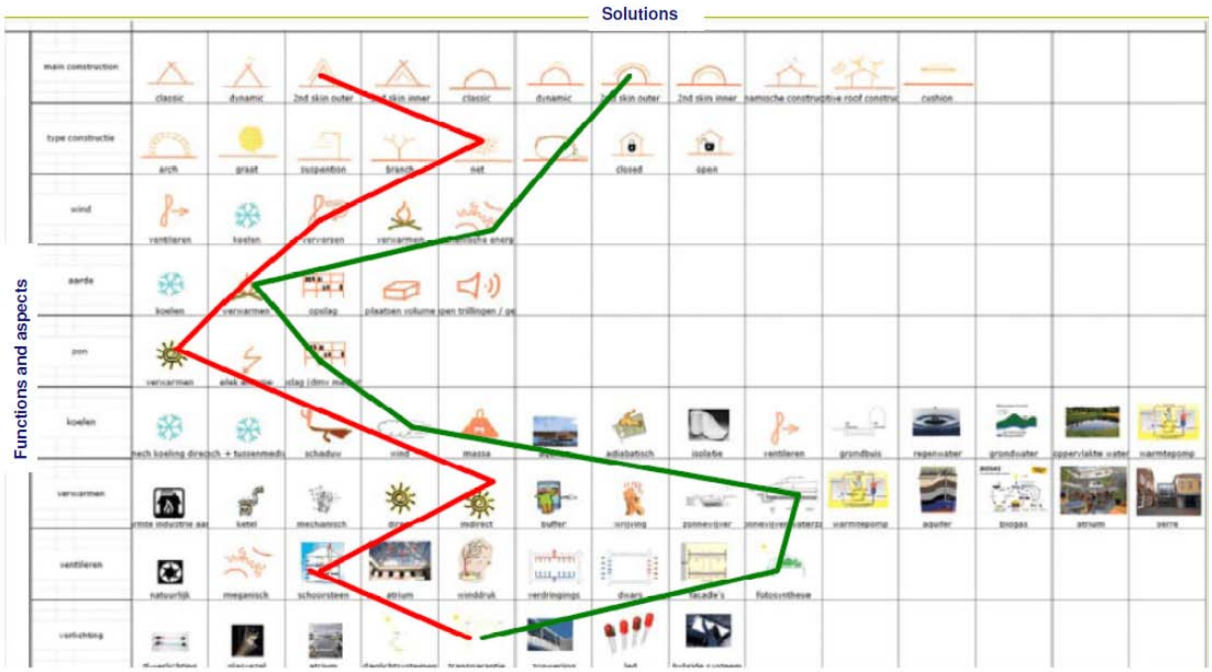

Figure 2. Morphological Chart of active roofs

3 DATABASE

Due to interdependency between the actors (Latour 1987) knowledge exchange and sharing is needed that is showed in their interpersonal communication using preferred communication tools (Emmitt et al. 2009). An integral design management approach to support and facilitate designers in such design teams to improve collaboration has to focus on the process of conceptual design in order to increase the potential of creating higher transparent designs (product level). Such a design approach should easily link all suitable information and knowledge of all the involved disciplines (architects, engineers, contractors). Due to the fact that the information and knowledge comes from various disciplines, the information and knowledge collected, shows mostly different characteristics, related to various levels of abstraction. Levels of abstraction means the decomposition of information into levels of increasing detail, where each level is used to define the entities in the level above. For each domain of industry the infill of these abstraction levels will be different (Kroonenberg & Siers 1992). Supporting

collaborative design teams by tools that bring forward there specific knowledge was one of the topics and aims of the Euractive Roofer-research project.
Storing and structuring and maintaining such information enables concerned designers, contractors and roofers to exchange information and knowledge related to Active Roofs, efficient and effectively. The concept-structure was developed as part of a special design-project. The following list contains the most important requirements for the technical development of the Database-structure and the related website:

- has to assist, in the primary stage of the design, designer and constructor / roofer – from their own perception / point of view within the setting of collaborative design/engineering about the most relevant / important aspects of Active Roofs; in order to generate a better design.
- has to structure, in a synoptic way, information about design- and construction aspects related Active Roofs and show the relationship between these aspects.
- has to show the different users of the database/website in a user-friendly way, different possible solutions related to a specific aspects / topics about design- and construction aspects related Active Roofs.

By coupling the structuring Morphological Charts as part of the Methodical design method of van den Kroonenberg the lay-out of the database was designed which fulfilled the requirements related to knowledge management. The roofers compared to designers need more specific technical information about specific subjects related to realization knowledge: assembly, safety, maintenance. Designers need more global information object knowledge related with options and possibilities (orientation, form, physical aspects etc.). By structuring specific knowledge related to the specific users in relationship to working on different abstraction levels, individual users as well as collaborative use of the database should show in a transparent way knowledge gaps and available knowledge about aspects and possible solutions of active roofs. The structuring method in a database makes it also possible to secure and maintain the used and added information in the database which can be offered to the different users within a qualified and uniform standard and building performance aspects for design and realization aspects. This makes the lay-out of the database a suitable foundation for using it as a tool for team-communication about the design and realization aspects for active roofs.
The database layout has a structure that makes it possible for designers, contractors and roofers to work with the same information-basis with a connection to the specific aspects related to their needs. By searching from each perspective (designers and builders), the information for the roofer might end successfully with design information and for the architect with construction-information. The designer can also use more specific information which will provide better insight in the specific detailed technical and construction aspects (see Fig. 3).

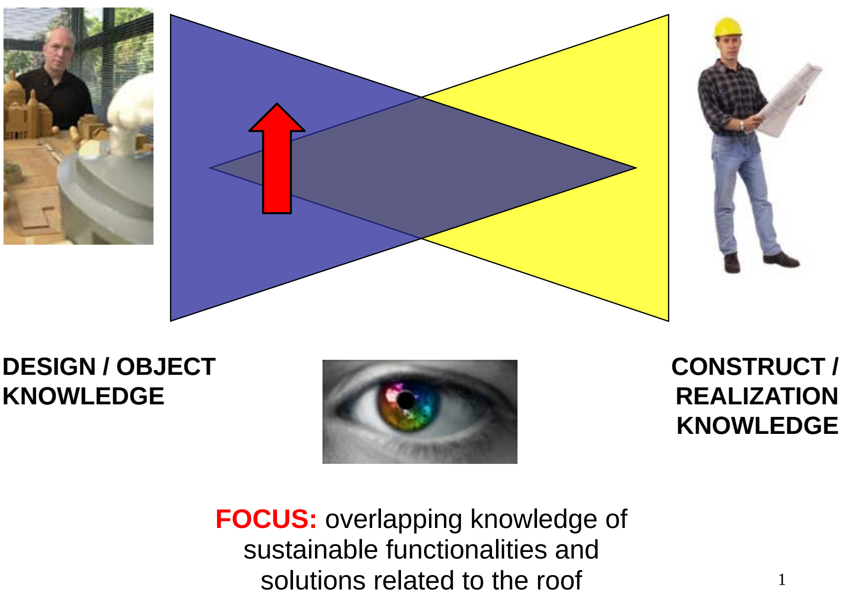

Figure 3. Interaction between design and construction

Aim of the database: give insight of knowledge fields of design / object knowledge to contractors and construct / realization knowledge to designers related to the design process. Left side of the figure is the starting point where the architect has the most knowledge about a broad field of design and less construct-realization knowledge (left triangle). For the roofer this is vice versa, symbolized by the right triangle. To broaden the overlapping knowledge field is the aim and focus, symbolized by the overlapping of the two triangles. The method of Morphological Charts is used to support the structure and lay-out of the database. This tool arranges functions and options with possible solutions related to these functions and options. Functions can be related to more abstract design aspects to more specific detailed aspects of construction.

The main user types are designers and constructors / roofers. The constructors / roofers need more specific information with specific subjects (assembly, safety, maintenance), whereas the designer needs more global information with options and possibilities (orientation, form, physical aspects etc.). The database structure / web-site has a structure which makes it possible for both designer and constructor / roofer to work with the same information-basis with a connection to the specific aspects related to there background. By searching from each 'direction the information for the constructor / roofer can end with the design-information, and for the designer with construction-information.

The designer can use more specific information to give him better insight in the more technical and construction aspects. Here is chosen for a morphological overview to support this way of working.

Basis of the information-structure is that of the morphological overview. This 'neutral' tool structures functions and several options / possible solutions related to this function. Functions can be related to aspects / subjects of different abstraction: from more abstract design aspects to more specific detailed aspects of construction (table 1 to 3).

Table 1.

Active roofs		
design aspects for roofs (tabel 2)	sustainable sources on roofs (tabel 3)	efficient use of roofs

Table 2.

up

Design aspects
Oriëntation
Building
Physics
Appearance
Materials

Table 3.

up

roof type \ source	solar energy: active	solar energy: passive	wind energy	environmental heat
flat roof	active solar on flat roofs	passive solar on flat roofs	wind energy on flat roofs	on flat roofs
sloped roof	active solar on sloped roofs	passive solar on sloped roofs	wind energy on sloped roofs	on sloped roofs
single bent roofs	active solar single bent roofs	passive solar single bent roofs	wind energy single bent roofs	single bent roofs
double bent roofs	active solar doubel bent roofs	passive solar doubel bent roofs	wind energy doubel bent roofs	doubel bent roofs
hanging roof	active solar	passive solar	wind energy	

The Database will be used primarily by designers and contractor / roofers within the setting of Collaborative Design as a supportive tool for designing Active Roofs. The layout of the Database for active roofs has two main access paths; one from the object-knowledge axis (design aspects for roofs) and the other from the realization-knowledge axis (efficient use of roofs). Third ‘connecting’ axis is that of the sustainable energy sources (see Figure 4). For each axis the main functionalities and aspects are classified. Related to this classified functionalities, sub-functionalities and solutions are generated. This classification and research for solutions was done through literature study and feed-back-meetings within the Euractive Roofer research. The first view from the user starts with the 3 axis as a choice (Fig. 4). Within each axis there is the possibility to search from a higher level of abstraction to a lower level of abstraction, with choices from the user (see Fig. 5 till 8).

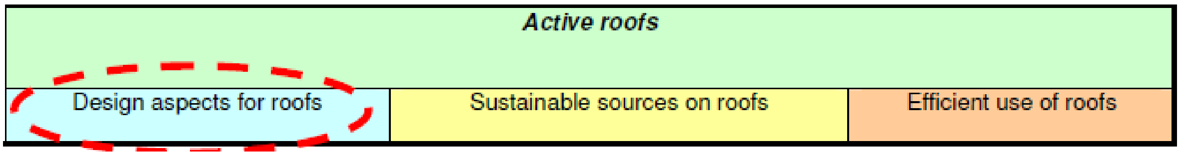

Figure 4. Starting point for the Web-based Data Base; Object- and Realization Knowledge through design aspects, sustainable sources and efficient use of roofs..

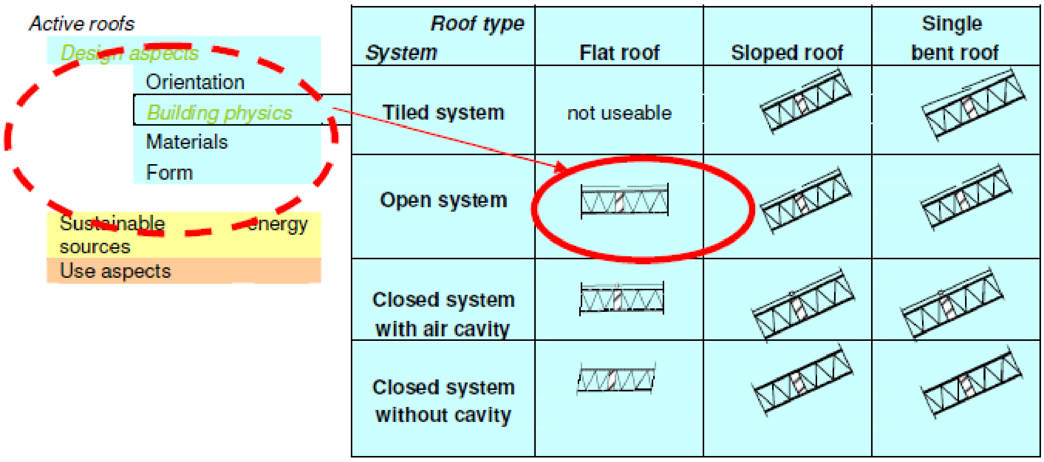

Figure 5. Within the axis of Design aspects, the next abstraction level is visible; orientation, building physics, materials and form.

For building physics the next morphological overview of functionalities and solutions is available. By choosing one of the solutions the next abstraction level can be viewed.

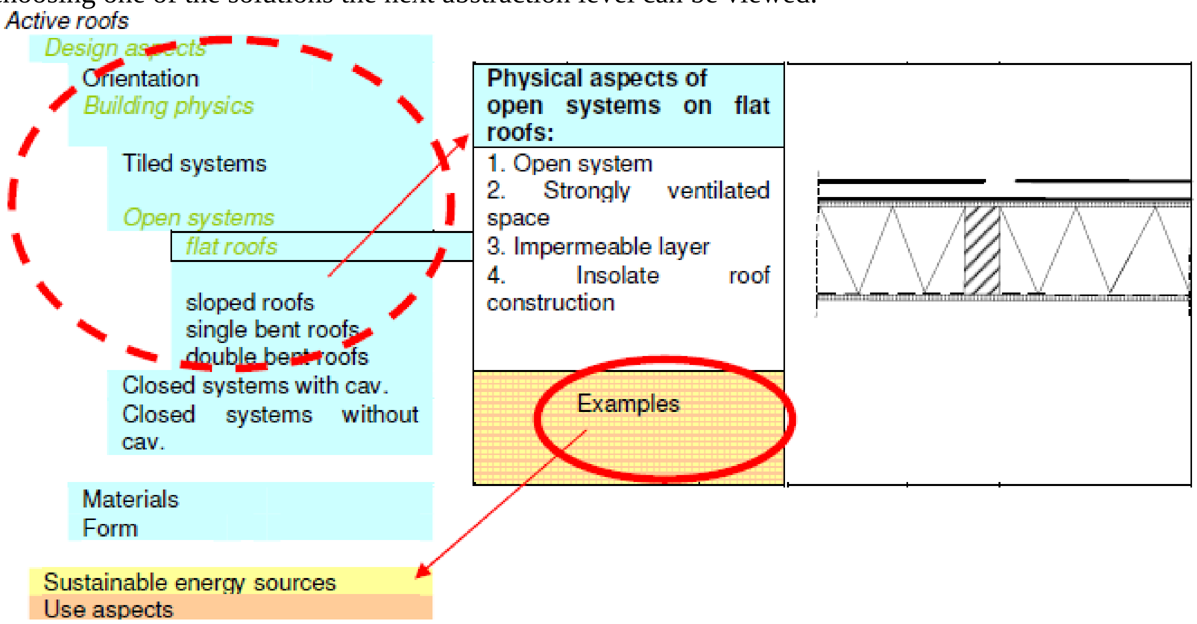

Figure 6. Choice from Morphological Overview for Building Physics. (figure 4); open systems - flat roofs the relation to Sustainable energy sources is linked (figure 6).

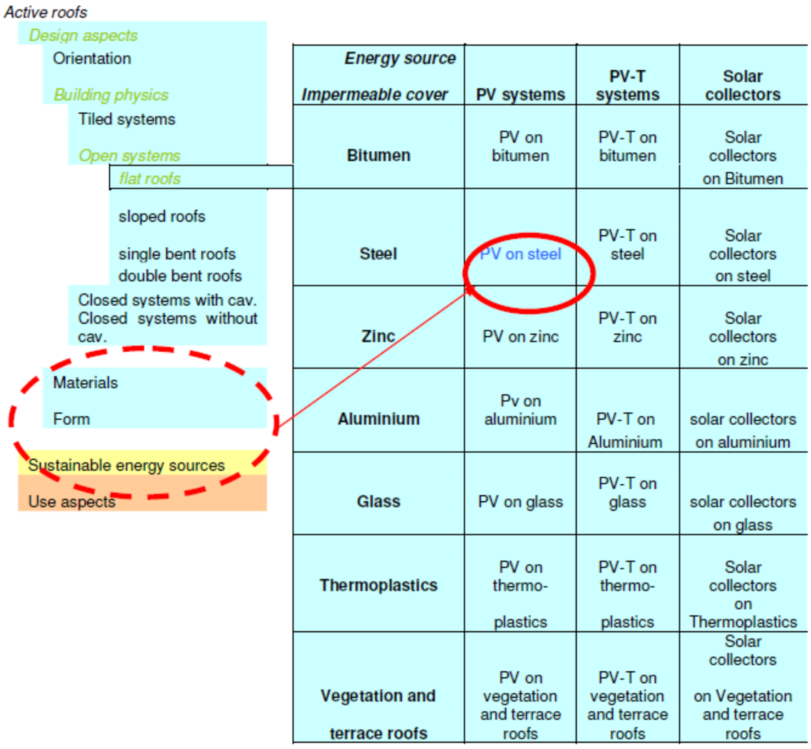

Figure 7. Morphological Overview for Sustainable energy sources to open systems – flat roofs.

By choosing one of the possible solutions the next level of abstraction is viewed – user aspects (Realization knowledge). By choosing one of the functionalities shown (assembly, maintenance or safety) the next detailed level is viewed, see Fig. 8.

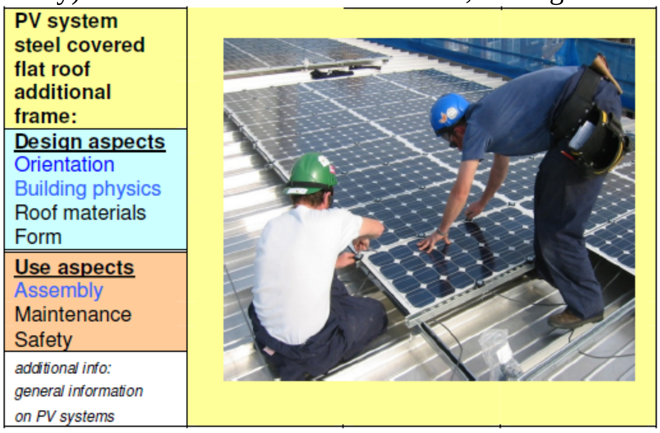

Figure 8. Final information level with specific instruction to the application

4 EXPERIMENTS

As part of the Euractive Roofer-research the Technical University of Eindhoven (TU/e), organized a workshop for professional Architects and Roofers. Each discipline was represented by 9 participants. The participants could participate in the workshop freely, with the only restriction that they should have at least 10 year project- and process-experience to assure a comparable competence profile of the participants. The participants were not informed about the research-connection of the workshop before attending; the focus of the workshop was on Collaborative Design for Active Roofs. The one-day arrangement of the workshop was used to work with two support design tools for Collaborative Teams; Morphological Overviews and the described Database. For the use of the Database this was done first by individual use and then in the collaborative setting of architect and roofer. As well for the individual as for the collaborative design task there was one hour available. Three different approaches were offered the participants to fill in the questionnaire. By using and discussing the Database individually and collaborative for designing Active Roofs a comparison was made. After the two design sessions the results were discussed with all participants. There was a laptop available for all participants with a connection to the Web-based Database.

5 RESULTS: WEB-BASED DATA BASE AND PRACTICE

Figure 8 shows the results for the questionnaire which was used to determine the different aspects of the use, functionalities and solutions related to the Database. First two rows show the results for individual use of the Data Base by Architects (A) and Constructors /Roofers (C).The third row shows the collaborative setting results for Architects and Constructors/Roofers working together T).
The possible rating for each question was from 1 to 5, were 5 was for the best rating. The average is based on 80% of the participants who filled in the questionnaires. The first six questions are related to the overall structure of the Database (Fig. 9). The second and third parts were questions related to two specific approaches; PV-systems and Active Energy Systems (Fig. 9). Overall there are no big differences between the individual ratings of the Architects and Roofers. Obvious is the poor rating by Architects for the completeness of Design- and User aspects.

	Structure search-menu	Completeness of Design-aspects	Completness of User-aspects	Quality of information presented	Design and construct related to PV-systems	Database useful / compatible to your discipline	Functionalities related to PV-systems	Work-methods related to functionalities	Functionalities related to active-energy-systems	Work-methods related to functionalities
A (individual) average	3,5	2,5	2,5	3,0	3,0	3,8	3,0	3,0	3,5	3,3
C (individual) average	3,0	3,5	3,0	3,0	3,0	3,8	3,3	2,8	3,1	3,0
T (team's collaborative) average	3,3	3,0	2,8	3,0	3,0	3,8	3,2	2,9	3,3	3,2

Figure 9. Overview of questionnaire about the functionalities and solutions of the Web-based Data Base.

6 CONCLUDING REMARKS

In this paper the layout and arrangement of a Web based database for active roofs was described and explained in its functioning and the process of development of this concept. Collective electronic tools like a projectwebsite package are handy and flexible for the proposed functioning in a design team. By organizing the team, in such a way that the flow of information and knowledge is using the database in every days work, frequently for storing, maintaining and adding new information, collaboration might be supported greatly. Although the layout and arrangement of the database is highly important, the most important aspect for using such tools is to motivate the team to use it in the way as it is proposed (Otter, 2005).
In the open questions of the questionnaires remarks were made by the architects that led to the conclusion that architects looked on the design aspects of active roofs broader than the offered functionalities and solutions. In the collaborative setting there are no big differences with the individual questionnaires. Important remarks from the participants came mainly from the architects, for the constructors/roofers it seemed to be a good and complete set-up with clear and useful classification, functionalities and solutions. For the main part of the architects three main topics were problematic or missing; the possibility to add functionalities and solutions, to compare solutions and integration with other building aspects and functionalities such as construction or costs and investment on return related to different options.
The integral design workshops as presented, in fact is a bottom up management approach. It can be expected that it will help and stimulate the participants in use of the tool while its usefulness will become more clear and transparent for the participants. However the tool(s) are still in an design stage,

they are not tested in practice in design teams yet on its functioning, user friendliness and its strength and weaknesses. Based on the reactions of the designers and roofers present in the workshop the expectations are that the attractiveness of the tool will pull the users for use in daily work. Ideas for future research are: adoption of the tool in practical situations; performance measurement based on the frequency of use and the output for both designers and contractors.

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REFERENCES

Aken J. van, 2005, Valid knowledge for the professional design of large and complex design processes. Design Studies 26(4) 379-404.

Argyris C., 1999, On Organizational Learning, Blackwell Publishers, Oxford, UK.

Dinten W.L. van, 2006, Met gevoel voor realiteit, over herkennen van betekenis bij organiseren, Delft, Eburon Academic Publishers.

Dixon N., 1999, The Organizational Learning Cycle, How we can learn collectively, Hempshire, Gower Publ. Ltd, UK.

Emmit S., Gorse C.A., 2007, Communication in Construction Teams, Taylor & Francis, London.

Emmit S. Prins M., Otter A.F., 2009, Architectural Management, Research and Practice, Wiley, London.

Eur-Active Roofer, 2005, Sixth framework program-collective research, contract no.:012478.

Hatchuel A., Weil B., 2003, A new approach of innovative design: an introduction to C-K theory, Proceedings ICED, Stockholm.

Jones J.C., 1970, Design Methods, John Wiley & Sons Ltd, Chichester.

Korbijn A., 1999, Vernieuwing in Productontwikkeling, Strategie voor de Toekomst, STT62 Stichting Toekomstbeeld der Techniek, Den Haag..

Krick E.V., 1969, An introduction to engineering and engineering design, Wiley, London.

Kroonenberg, H.H. van den, Siers, F.J., 1992, Methodisch ontwerpen, Educaboek BV, Culemborg.

Latour B., 1987, Science in Action, Open University Press, Milton Keynes.

Lawson B., 1980, How designers think, Architectural Press, London.

Nonaka I., Takuechi H., 1995, The knowledge creating company: how Japanese companies create the dynamics of innovations, Oxford University Press, New York.

Otte, A.F.H.J. den, 2005, Design Team Communication and Performance using a Project Website, PhD-thesis, Technische Universiteit Eindhoven.

Paashuis V., 1998, The Organisation of Integrated Product Development, PhD-thesis, Springer, Berlin

Reymen I.M.M.J., 2001, Improving Design Processes through Structured Reflection: A Domain-independent Approach, PhD-thesis, Technische Universiteit Eindhoven

Ritchey T., 2002, General Morphological Analysis, A general method for non-quantified modeling, Adapted from the paper "Fritz Zwicky, Morphologie and Policy Analysis", presented at the 16th EURO Conference on Operational Analysis, Brussels, 1998, the Swedish Morphological Society, www.swemorph.com.

Savanović P., 2009, Integral design method in the context of sustainable building design, PhD thesis, Technische Universiteit Eindhoven.

Zeiler W., Quanjel E., Savanović P., Borsboom W., Trum H., 2005, Integral Design Methodology for the Built Environment, Proceedings Design Research in the Netherlands, Eindhoven.

Zwicky F., Wilson, A.G., 1967, New Methods of Thought and Procedure, Contributions to the Symposium on Methodologies, Pasadena, New York..