INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

RESEARCH METHODOLOGY FOR INTEGRAL DESIGN IN THE CONTEXT OF COLLABORATIVE ENGINEERING FOR ACTIVE ROOFS

Emile Quanjel[1], Wim Zeiler[2]
[1]Technische Universiteit Eindhoven (TU/e); Architect, Delft
[2]Technische Universiteit Eindhoven (TU/e)

ABSTRACT
In the world of design and engineering, gaps of knowledge between these disciplines are recognized [1, 2, 3, 4]. The learning capacity of the building industry – as well as in other industries – is becoming a main issue, also within Architect-organizations [5, 6].

A model for structuring knowledge on different abstraction levels is found in Methodical Design, a system theory based on the combination of the German design school [7, 8, 9, 10, 11, 12] and the Anglo-American school [13, 14]. Methodical Design is a problem oriented model based on functional hierarchy, which can be applied on several levels of abstraction and makes it possible to link these levels of abstraction with the phases in the design process itself [15, 16, 17, 18].

This paper describes the research methodology, based on Methodical Design, as used in a doctoral design related to practice and the 6th European framework research project EURACTIVE ROOF-er. The research methodology – as quasi-experimental design – uses the structuring method of the Methodical Design to investigate how this specific design method and associated design tools can support the collaboration between designers and engineers [19].

Keywords: Approaches & Rationales in Design (Collaboration)

1 INTRODUCTION AND PROBLEM DEFINITION

Gaps of knowledge between the worlds of design and engineering in the Building Industry are recognized by researchers as well as practitioners [1, 2, 3, 4, 5, 6]. Learning capacity is identified by several researchers as the basis of knowledge development in design teams and projects [20, 21, 22]. Knowledge development in daily practice starts with effective collaboration between the participating disciplines of the design team [23, 24, 25, 22, 26], making designing the most central activity in engineering a new product [27, 28, 3]. The basis of a design process is concept generation; this is the natural habitat for designers for finding possible product solutions [29]. Most important decisions for the product / product-life-cycle are usually made in the conceptual phase of the design – the early design phase – even though not all relevant information, knowledge and participants are available then [30, 31]. For solving complex design problems, creative concept generation involves multi-disciplinary approach of experts in a team-setting [19]. Thus multi-disciplinary teams will generate a larger variation in objectives than individuals and mono-disciplinary teams [32] and a wider range of solutions [33]. A wider range of objectives and solutions increase the possibilities of innovative designs that better suits clients needs. Concept designs can be seen as the basis of knowledge development within the design-team related to specific design solutions [34, 35].

Although the learning capacity of the total Building Industry is insufficient [30, 36], a lack of innovative designs is observed in a specific part of the Building Industry; traditional roof design. Professional parties indicate that this lack of innovation might be caused by a sub-optimal interaction between 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 engineer / roofer, a contradiction in knowledge-flow between disciplines with different educational background [37]. For centuries the roof has been the part of the total building design which has basic functions of physical protection (wind-rain-snow) and is now used more and more for storage of comfort-technology (HVAC etc.). Roof design / engineering with all its existing – traditional – and new functions and applications related to the comfort-aspects of the total building, are usually handled as separate and add-on aspects in design as well as in practice. Traditional process-approaches might no longer suffice, because complexity and scale of design processes continuously increase through time and quality [38, 39, 35].

Many studies related to multidisciplinary team collaboration have been conducted, focused on a variety of topics related to knowledge exchange / development. Beside the more general studies [20, 21, 22], there are studies that examine team designing [40, 41, 42, 43, 44] concerning face-to-face collaboration. Other important research studied the effects of different media on collaborative design and focused mainly on communication. [46, 47, 48, 49, 50, 26]. Related studies where done on shared understanding, representation and tools [40, 51, 52, 53, 50]) and knowledge transfer in collaborative settings [54, 55]. Overall, however, little attention has been given to the role and nature of external representation and knowledge exchange / development in the collaborative design-process between participants coming from different educational backgrounds (architect and roofer), with great differences in competences and skills (fig. 1.).

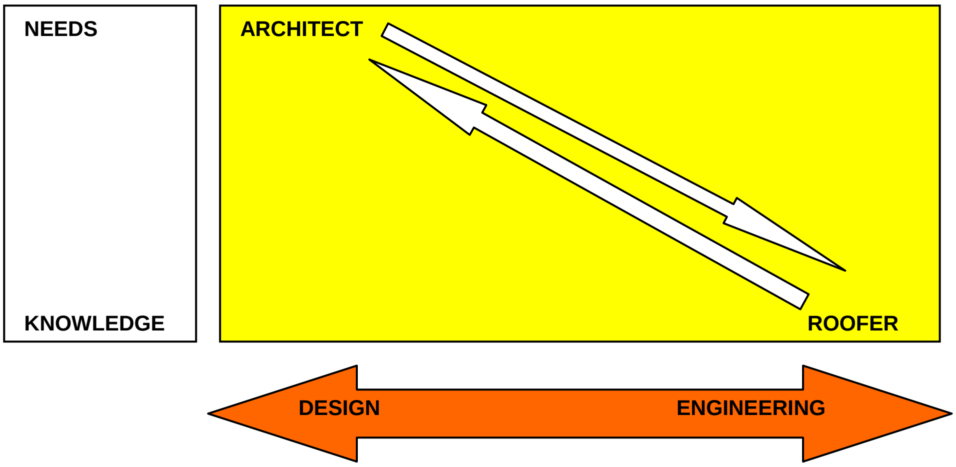

Fig.1. Relationship of needs and knowledge of architect and roofer, from engineering to design

2 OBJECTIVES

The main objective of this research is:

- How the knowledge exchange / development between designer / architect, engineer / roofer of innovative roofs – as part of the total building design and its comfort-systems and within the context of the Dutch building construction industry – is realised in the early design phase
- What is the influence of a supportive knowledge exchange tool – as part of a specific design model – on the knowledge exchange / development in the former setting

Hypothesis: using a specific structuring method for designing, will improve the possibilities of the necessary knowledge exchange and knowledge development as stated above.

3 METHODS: DEFENITIONS PHASE

The proposed method is based on the Methodical Design model, with its typical and exceptional characteristics related to the subject The Methodical Design method is based on system theory and a combination of ideas of the German design school [7, 8, 9, 10, 11, 12] and the Anglo-American's, [13, 14]. Methodical Design combines German and Anglo-American process model approaches. Methodical Design is a problem oriented model based on functional hierarchy, which can be applied on several levels of abstraction and makes it possible to link these levels of abstraction with the phases in the design process itself [15, 16, 17, 18]. The essential element in this model is the design process [17]. The characteristics of the design process can be split up into those related to: strategies, stages and activities. Within the setting of Methodical Design several design-support tools are used: the morphological overview [56] and the Kesselring-method [57]. These are practical tools to structure several functionalities, generate and select possible solutions and can be used for different aspects and abstraction levels.

Related to the type of knowledge and the team-collaboration – in different settings and between different team-members – the focus on explicit 'object knowledge' [35] generates the information which makes clear how the contribution of the discipline based object knowledge is communicated and how this knowledge is transformed into the design concepts. By comparing the use of the Methodical Design within the setting of multidisciplinary collaboration – with and without using this specific method – provides a better insight in the effect of the structuring method on this specific knowledge exchange in a practical setting between architects and roofers. The research setting combines the theoretical method of rational problem solving [58] with the reflective practice [20, 59, 3] as a framework for exploration and improvement [60].

Primal aim of this research is to provide significant insight, within the setting described above, into the knowledge development and the influence of the use of Methodical Design and its tools on this development. Both the combination of theory and practice as well as the use of a specific design method in relationship to knowledge development, makes it necessary to first indicate the right items within this research concept. The research design will help to determine the best data collection method and selection of subjects related to the problem. Through this quasi-experimental design [19] comparable experiments result in validated 'measurements' and indications of the 'why', 'how' and 'when' [61]. The working principle of the research will follow the steps, as by a design with it's double loop learning [22], of analyzing / synthesizing – selection / modifying [17, 31].

By using 4 different levels of abstraction as formulated as functionalities of the problem – integral design / collaborative engineering / sustainable comfort systems / active roofs – the research has a clear framework. Within each level of abstraction - though the research is about developing a methodology for design collaboration - the approach for developing edge conditions and possible approach is the same. This is applicable as well for the research methodology as for the design methodology. For each level the approach (analyze / generate / select / modify) is similar, the development will be different.

Within the Methodical Design, the relationship of the several functionalities and steps can be shown in the scheme below (fig. 2.). In order to structure the research for each level of abstraction (integral design / collaborative engineering / sustainable comfort systems / active roofs) there will be a problem definition / working principle to develop solutions / choice of developed solutions / shape of chosen solution (blue arrow) – for all the functionalities related (vertical column / green arrow).

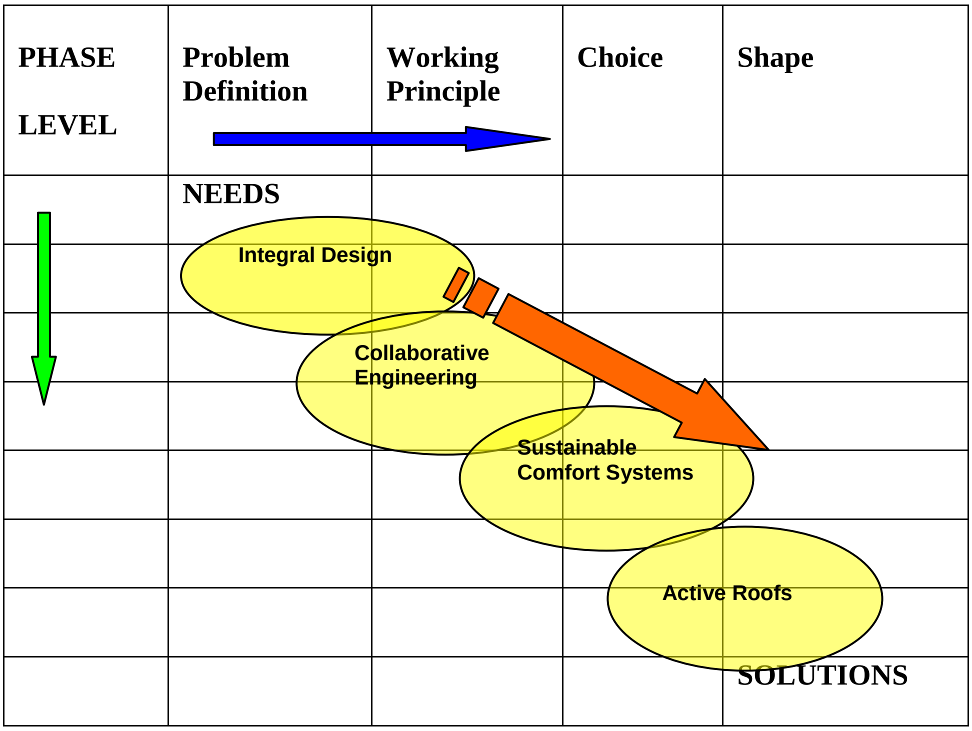

Fig. 2. The modular system of hierarchical abstraction as basis of the research methodology

As shown in figure 2, the problem definition generates the working principle for the research methodology. For each level of abstraction within the defined research topic, the several stages and their specific functionalities / needs have to be taken into account. These stages will be described in this paragraph.

The integral approach of the research methodology means different viewpoints on the same topic [31]. For this research the two main viewpoints are that of the designer – the architect – and the engineer – the roofer. By using different typologies of quasi experiments – case studies, scenario's and design task workshops – comparing, verifying and clarifying these experiments, also on research level the different viewpoints are used. By using quasi-experiments, step by step a next – more concrete abstraction level – will be analyzed and verified in order to get a clear view on the influence of the several functionalities / needs related to the specific abstraction level (Integral Design / Collaborative Engineering / Sustainable Comfort Systems / Active Roofs).

The method of triangulation of data is used to derive valid and solid explanations for important practical aspects related to the knowledge exchange / development:
- First the competence profiles – as actual state of needs for the disciplines involved;
- Second a database-structure – as a possible way to structure and contain the knowledge for both disciplines;
- Third by the results of case studies – to show how practical problems between building design in relationship with engineering aspects are handled [61].
The outcome of this triangulation will supply information about the effect of the use of the proposed Methodical Design and its tools (analyzing part).

Before investigating solutions of ‘bridging the gap between architects and roofers, the research will start with investigating the needs and knowledge which causes this gap of design solutions and application engineering. Therefore the following analysis is made:

- needs in primal design phase for designers / architects
- supply / knowledge from engineers / roofers
- analysis of the differences and similarities between needs and skills of both disciplines

By analyzing all these aspects, an overview of which functionalities are necessary for possible design decision tools to support the participants (architect and roofer) in the setting of collaborative engineering, will be generated (fig. 3.). Through this first step a further analysis of the roof engineering / installer industry is possible, to develop a model of competence profiles. This model will show which steps are necessary, as a path to success, for creation of appreciation for this specific industry on different levels in the context of collaborative engineering: organization / process / product-level. To have a reference with practice the competence profile of the façade engineering / installer industry, as a successful path-to-success, is used.

Next step is to set up functionalities related to design- and engineering aspects and generate them in a database useful for both architects and roofers. Related to the different users, two different menus are developed to search and combine the knowledge needed, to design and/or engineer an active roof. The database will be developed in a web-based-setting to facilitate the different users with the needed knowledge, related to design and engineering active roofs.

From the practice, case studies are used to show which kind of problems are there in the traditional design process for roofs and facades, as part of the total building design, in relationship with engineering aspects. Three different projects will be analyzed (to prove the assumption of the problem);

- comparison of traditional process and collaborative process-approach
- SWOT-analysis with focus on communication and information sharing
- in relationship with architectural concept product/system requirements and technical facilities
- determine criteria of specialist interaction aspects of collaborative design and engineering
- feed-back for aspects of a competence-model and aspects engineering knowledge supply for roofers in the design process.

The designed competence profile will be used to set up several, process-based scenarios, used for testing and modifying the data-base-structure as part of Methodical Design methodology. The experiments for testing will redefine the data-base-structure and give a more precise view on the influential and important aspects and functionalities of the knowledge needed in the primal design/engineering phase. Through these steps more precise aspects which are necessary for using more optimal the Methodical Design Tools and Database, can be developed. (fig. 3.).

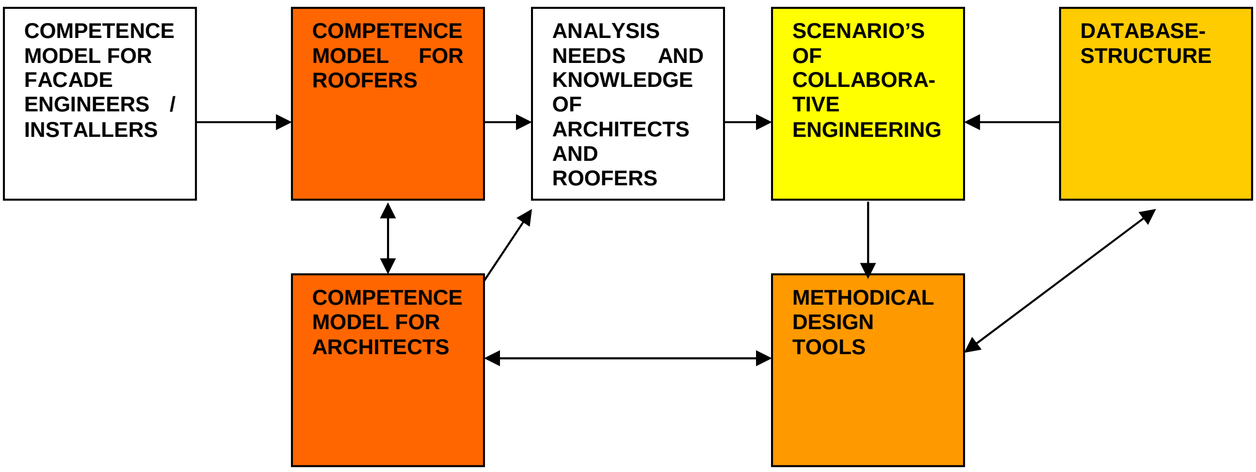

Figure. 3. Process scheme for designing / engineering active roofs

Crucial point by using the experiments, in relationship to the 'theoretical model of the Methodical Design, is the connection to a 'realistic model which is part of the design-practice.
For constructive implementation / exchange of knowledge within the design process there are 3 main different possibilities of knowledge exchange / generation:

- reflection in action [20]: which connects the design situation in interaction with a framework for the several disciplines
- shared knowledge – heterogeneous engineering [62, 63]: a process of aligning cognitive and social-political elements to create and realize a good design
- 'bricolage' [64, 65, 66]: the use of situational resources tendering with the resources at hand.

The setting which is chosen is that of 'the reflective practice [20, 67]. This setting has characteristics which makes it, comparing to the other two possibilities, a realistic setting which we can use to verify and validate our theoretical model of Methodical Design. It is a setting which inhabits characteristics to, as in a design-process, have a rational feed-back on the former design-steps and design-decisions and to support the next design-steps and –decisions in a realistic setting with several disciplines.

Mostly the verification of a new methodological concept is done by experiments with student groups (novices) [68] or with design groups within one company [69]. The relevance of the research methodology for practical use in a realistic setting is improved by using experienced designers and participants (professionals), as there is a major difference in approach between novice and experienced designers [70, 71].

4 METHODS: CHOICE / SELECTIOIN PHASE

With the found functionalities from the Working Principle – in relationship to the use of the Database-structure and Methodical Design – the scenarios for a serial of quasi experiments will be set up and modified. This is a set up for a prescriptive method to develop appliances for supporting the collaborative design- and engineering-process in combination with engineering knowledge supply.
The quasi experiments will have the focus on the following aspects:

- communication between the design- and engineering solutions for active roofs
- generation of more possible design / engineering solutions for active roofs
- the use of the support decision tool to generate these design / engineering solutions

The same format, related to the Methodical Design, will be used for the set up of the quasi experiments as well for the verification and clarification.

The quasi experiments will be build up in a step by step format with alterations on the group setting (collaborative engineering), group tasks (use of sustainable comfort systems, design /engineering active roofs). The experiments will have the format of design task workshops and/or master classes related to design tasks. The same methodology used on the level of research as a whole is also used on the other abstraction levels within the research; in this case the quasi experiments and the verification of these quasi experiments. (fig. 4.) As example, related to the setting of Collaborative Design and the use of the Database and / or Methodical Design tools we can define the following functionalities / needs related to these quasi experiments:

- situation of the design-team without the use of database or methodical design tools
- situation of design team by using database or methodical design tools, without training
- situation of design team by using database or methodical design tools, with training

The experiments will be done in a serial with feed-back; comparison / selection of the type of experiments as the use of several verification methods as well as the results of the quasi experiments itself. The specific functionalities and results of the experiments will be verified with the use of different verification-methods. For this purpose the Kesselring-method [57], as part of the Methodical Design Methodology, is used. The Kesselring-method is a neutral way to compare / select several different experiments, related to the aspects of realization (how easy / difficult is it to set up and realize the experiment) and function (what is the result of the experiment related to problem definition / working principle). (fig. 5.).

LEVEL / PHASE	Problem definition	Working principle	Choice	Modify
Experiment 1.1	NEED			
Experiment 1.2				
Experiment 2.1				
Experiment 2.2				
Experiment 2.3				
Experiment 3.1				SOLUTION

Fig. 4. Methodology for set up of experiments and verification, bases for needed results for clarification

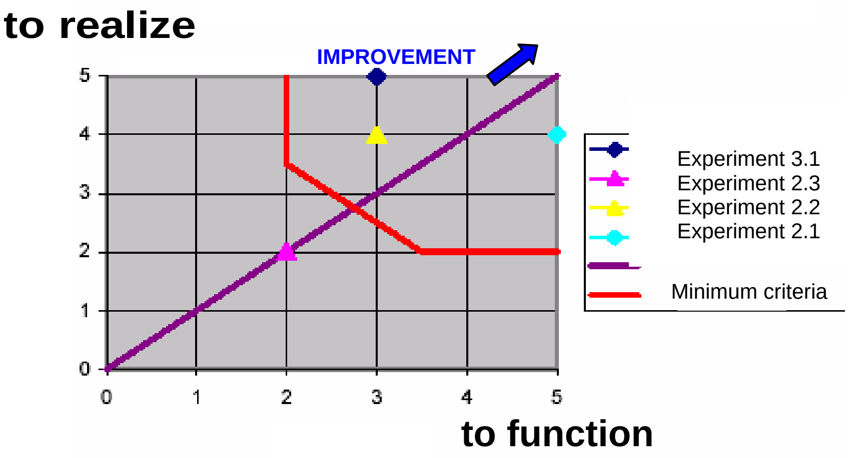

Fig. 5. Kesselring diagram: method of comparison / clarification; example
blue arrow gives direction of improvement of ‘best to realize / function experiment(s)

5 METHODS: MODIFYING PHASE

To distinguish the knowledge-exchange / development aspects related to the use of the tools of Methodical Design, several views are used to extract data out of design teams: by evaluation-questionnaires for all participants, video-registration / analysis of the experiments by using Bales' Interaction Process Analysis model (IPA) [72, 26] . It is expected that increase in interaction will be indicators for increase in knowledge exchange and sharing, because live and face-to-face communication is the richest communication to derive understanding between sender and receiver [73] (Daft & Lengel 1984). Referring to the basis of knowledge development in relationship to design solutions, the focus will be on the explicit object knowledge used by team-members for the specific design setting [35]. With the help of the Kesselring-method the relationship between realization and functioning of the experiments with the Methodical Design and its tools, are compared. It is assumed that this method generates success-factors for improvement. This final part is the reflective part of the research, the feed-back loop related to the design-research. Through this iteration process more insight in the knowledge exchange / development of architect and roofers is generated and possible improvement on the proposed method / tools can be made (modifying part).

6 EXPECTED RESULTS

The actual phase of the described research methodology is the selection-phase for defining and applying the case-studies and quasi-experiments. Final results of the research methodology are:

- greatly improved insight of knowledge-flows between designers / architects to engineers / roofers and visa versa; how do they exchange knowledge;
- identification of the influence from the specific method and its tools – Methodical Design – on the knowledge exchange / development between designers / architects and engineers / roofers;
- outcomes of the former aspects can be used, within a wider range of the EURACTIVE ROOfer project, as a training-set up used for knowledge exchange / development between design-team-members of Active Roof Design which inhabits the development of the Database structure and the Methodical Design Tools [37].

7 CONCLUSION

Although within this research design a relatively small number of experiments are going to be executed to generate valid statistic to provide sufficient evidence, indications will be extracted for the importance of these subjects and further research..

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Contact: E.M.C.J.Quanjel / W. Zeiler
Technische Universiteit Eindhoven
Department of Architecture, Building and Planning
Den Dolech 2, Vertigo 6.28
PO Box 513, 5600 MB Eindhoven
The Netherlands
Phone: +31 40 2473714
Fax: + 31 40 2438595
e-mail: e.m.c.j.quanjel@bwk.tue.nl / w.zeiler@bwk.tue.nl