

## **AN INTEGRAL DESIGN FRAMEWORK FOR MULTI-DISCIPLINARY DESIGN**

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### **ABSTRACT**

A comprehensive domain independent system-level perspective of conceptualization of design is a major driver for successful product development. Such a general design model, Integral Design, was developed based on a specific Dutch design method, Methodical design, which was aimed specifically for applications in the Mechanical Engineering domain. The design method was specifically developed with the help of experienced designers and is meant for young students in a multi-disciplinary design context, such as building design. Integral design provides a suitable framework, existing of phases and specific steps, for guiding users through the design process. It supports not only the designers but also helps them to make the process explicit and to communicate the actions and results to their stakeholders. The focus in this paper is on presenting the overall framework of the design method. In the Netherlands in several bachelor and master educational programs at Technical High schools and the University of Technology Eindhoven use this model to teach students mechanical engineering design and building services design. As such it is one of the most popular design methods in the Netherlands.

**Keywords:** Collaborative design, Design methods, Design process

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## 1 INTRODUCTION

Design of buildings is seen largely as an individual's creative act (Habracken 2005). Moreover, 'the belief that a single designer should be in control of all levels of environmental form' (Habracken 2005, p.89) is even a professional ideal. However, more and more it is realized that effective collaboration during the concept design phase in architecture provide the greatest potential for the overall success of a building project (Leon *et al.*, 2014). However, design deals with complex ill definite wicked problems which are difficult to solve. Therefore, it is important to give designers the right tools as well as a supportive process framework to order the design process. However, in the field of architecture there is a lack of a body of theory to support the study of architectural design method (Plowright 2014), which makes it necessary to review concepts from other foiled of study like mechanical engineering. Therefore we looked for a framework to support the activity of building design. In the early 1960's researchers and practitioners began to investigate new design methods as a way to improve the outcome of design processes (Hubka and Eder 2001, Cross 2007). A good historical overview is described by Pahl *et al.* (2006) and shows what step-wise development has taken place. Since then, there has been a period of expansion through the 1990's right up to the present day (Le Masson *et al.*, 2013, Chakrabarti and Blessing 2014, Andreasen *et al.*, 2015, Chen *et al.*, 2015, Atkinson & Oppenheimer 2016, Le Masson *et al.*, 2017, Lloyd 2017, Eisenbart *et al.*, 2017). It is important to provide a theoretical basis to encourage the strategic use of design methodologies as teaching strategies (Curry 2014) fully and strictly applied in industrial applications (Dorst 2016). It is better to develop a design method as close as possible to practice and with help of industry. Therefore, in 1999 the professional Dutch organization for architects BNA and consulting engineers NL Ingenieurs together with the University of Technology Delft and the Dutch Building Services Society started a research in close cooperation with industry to develop a design method to improve the conceptual building design process. Workshops with experienced professional were organized and step by step a new design method was developed and tested (Savanovic 2009). This Integral Design method was based on the methodical design approach, a system theory based method and elaborated (Zeiler and Savanovic 2009) in cooperation with the building industry into a complete framework of interpretation-generation-selection-shaping steps. Systematic Approach (Pahl and Beitz 2007) is generally seen as a prescriptive model of designing (Kannengiesser and Gero 2017) based on observations of professional design practice. Therefore, in this paper the developed Integral Design model is compared the Systematic Approach so see if it fulfils all required steps of the different phases as mentioned by Pahl and Beitz (2007) as well as to determine the specific contribution of the model to existing knowledge.

## 2 METHODOLOGY: METHODICAL DESIGN APPROACH

Integral Design is based on Methodical Design a design method developed at the University of Twente in the seventies by van den Kroonenberg (1988). When van den Kroonenberg developed his design method he had searched for universal principles of science and design as well as a common basis for interdisciplinary relationships for studying complex systems (Zeiler 2007). The focus was on the need for a methodical arrangement of the design activities in an overarching design framework and he looked at the differences between research and design in analogy with the general system theory. Ludwig von Bertalanffy created in the forties a systematic framework for the description of the general relations in the natural and man-made world, the General system theory (Bertalanffy 1956). General system theory provides a supporting framework for simplifying the complexity by making use of different levels of detail on the basis of hierarchy (Boulding 1956). The design process is seen as a chain of activities, starting with an abstract problem, the goal, and results in a specific solution: a solution which fulfils the required functions. Integral Design process begins with a description of requirements that the product should provide and ends with a completely described product as a solution that meets the stated requirement. This means starting with a very abstract description, step by step the whole design task becomes more detailed. The specific design steps are activities such as generating, synthesizing, selecting and design (Blessing 1994). The four-step pattern in Figure 1 shows the sequence of design steps (interpretation, generating, selecting and shaping).

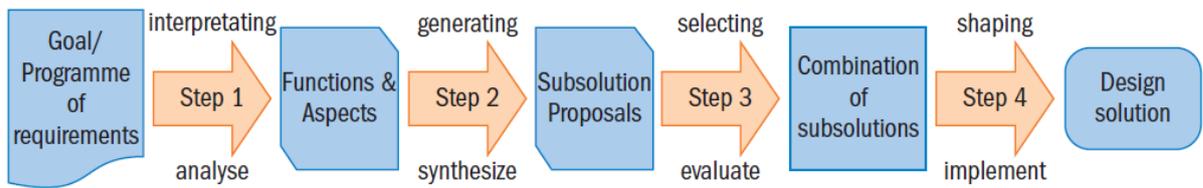


Figure 1. The four-step pattern of Integral Design (Zeiler 2017)

An important feature of the frame work of Methodical Design is that it leads to a better overview of the design process, making it possible to further reduce the difficulty of the design task by splitting the design process into steps. Designers need to avoid large process jumps because they may lead to ‘jumping to conclusions’ too fast. It ignores all the choices designers made unconsciously when leaping forward. With every choice, the designer should be able to see its effect or risks choosing a solution that is not working. Therefore, the process is split into four design phases: problem definition, method determination, selection and shaping. Certain steps are done in each of these phases that are aimed at the objective that applies within the phase. For example, in the first phase the design task is further analysed and specified: the problem defining phase. The next phase, method determination, focuses on the search for possible methods to arrive at a solution. A selection is then made in the third phase: the selection phase. The chosen solution or possible solutions can be further developed in the fourth and last phase: the shaping phase. The different phases are described in more detail in the next sections.

### 3 METHODOLOGICAL DESIGN FRAMEWORK

#### Phase 1 Problem definition

Before the start of the actual design process, it is often necessary to conduct a preliminary investigation. This is to get a better image of the identified need, as well as the demands and wishes of the client. An important aspect in the problem-defining phase, depending on the goal, is to further define the need that should be fulfilled, which is the true value of the design for the client. The problem defining phase is characterized by the actions necessary and split into four steps according to the principle of Integral design, as presented in Figure 2 (Zeiler 2017) as well as the corresponding steps of Pahl & Beitz’ (2007) Systematic Approach (Kannengiesser and Gero 2017).

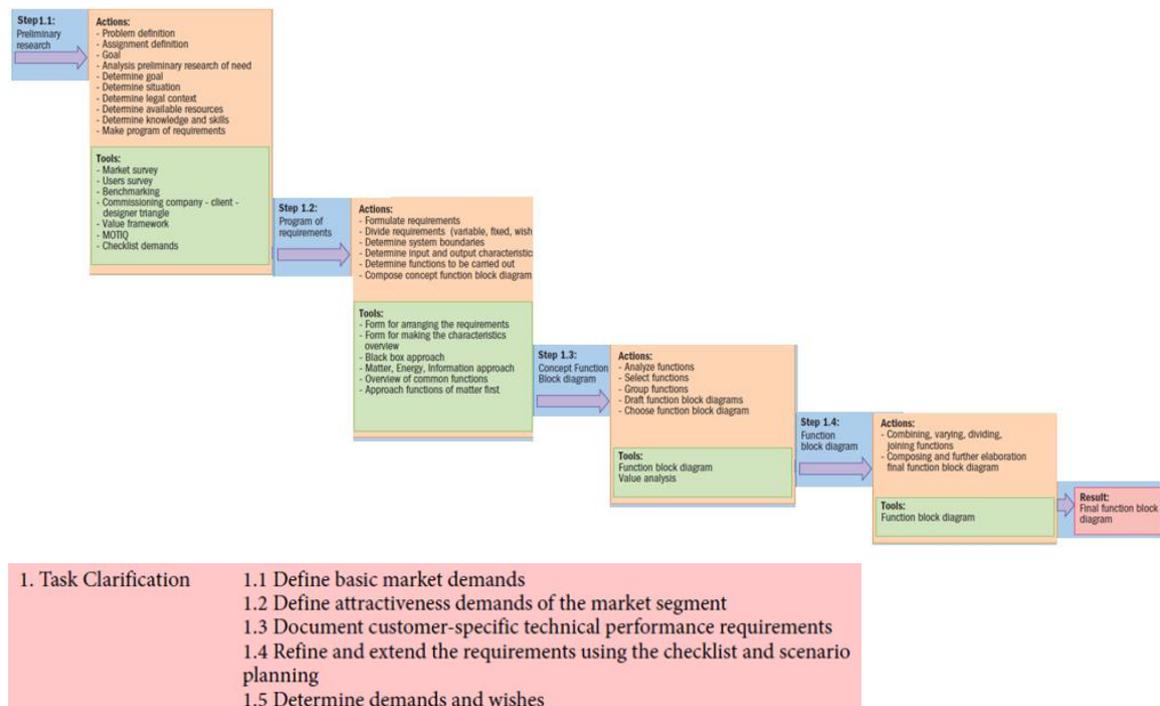


Figure 2. Main structure and steps problem definition phase (Zeiler 2017) and Task Clarification Phase (Kannengiesser and Gero 2017)

## Phase 2 Method determining phase

In the method-determining phase, first the possible methods are searched for to fulfil the various (sub) functions that were defined in the previous problem-defining stage. These methods can be combined in a number of combinations which can be presented as a principle sketch of the structure for the product or installation design. The result is a concept solution that can be presented as the structure of the technical device. Within the framework of methodical design, knowledge and insights from other methods can be used such as various creative techniques. To organize the various actions during the method-determining phase the plan of steps can use as a guide, see Figure 3.

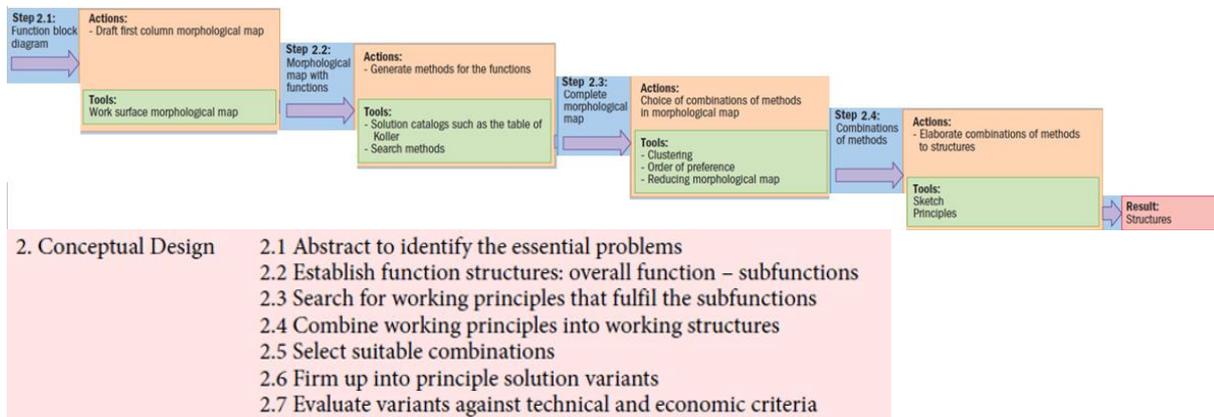


Figure 3. Main structure and plan of steps Method determination phase (Zeiler 2017a) and Conceptual Design Phase (Kannengiesser and Gero 2017)

## Phase 3 Selection-determining phase

As a result of your own creativity as a designer, combined with numerous application possibilities of creativity and search methods, several solution variants are created in the process- determining phase, see Figure 4.

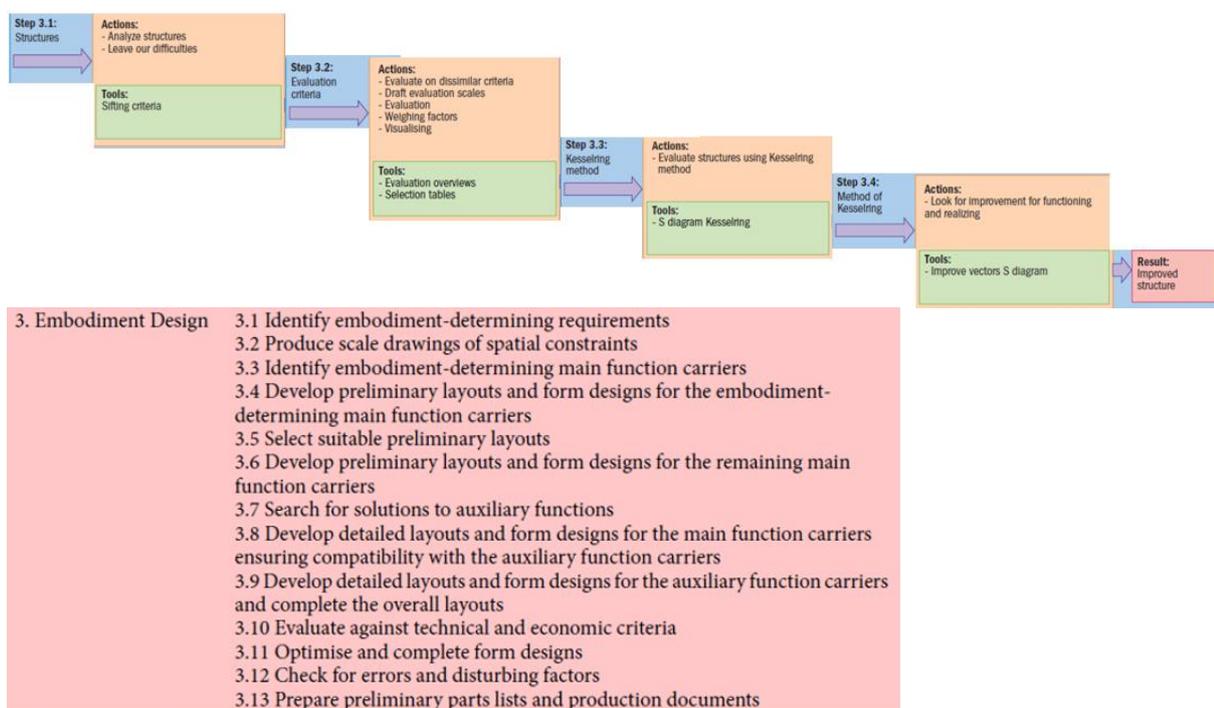


Figure 4. Main structure and steps of the Selection determination phase (Zeiler 2017a) and Embodiment Design Phase (Kannengiesser and Gero 2017)

## Phase 4 Shaping phase

In the shaping-phase, the following has to be discussed in conjunction with each other: the choice of the material, the choice of the manufacturing process and the desired dimensions, which based on the loads determine the final shape. To support this process also here the phase is split into different steps, see Figure 5.

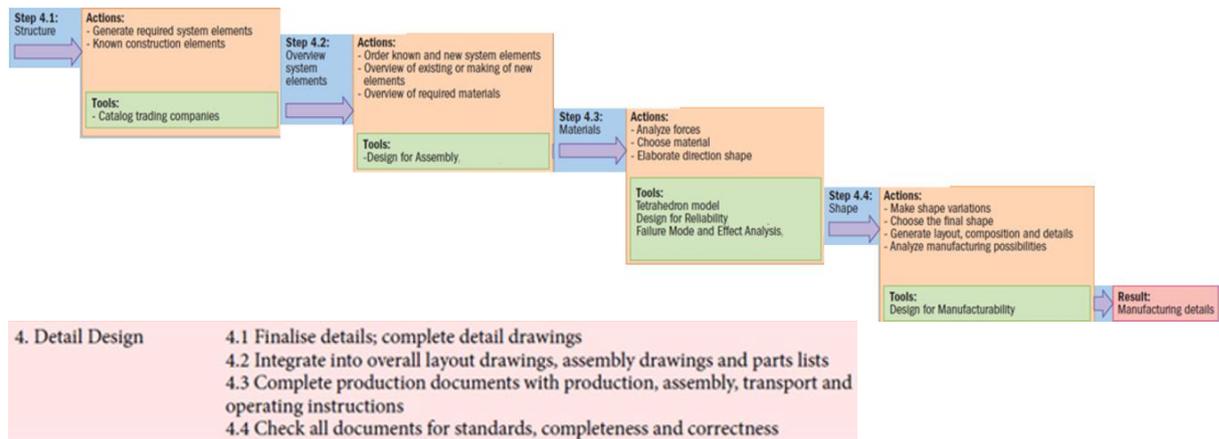


Figure 5. Main structure and steps of the Shaping phase (Zeiler 2017a) and Detail Design Phase (Kannengiesser and Gero 2017)

The proposed methodical design framework include all the different Phases of the Systematic Approach by Pahl and Beitz (2007), however there are also some difference. Especially in the Task Clarification Phase some task are already done in the Problem definition phase, while in the method - determination phase already steps are done which occur only in the third Phase of Embodiment Design. Overall the analogy with and the completeness compared between the two different approaches is good.

#### 4 COMPARISON: ADDED VALUE OF INTEGRAL DESIGN

Integral Design like Methodical Design makes it possible to connect the levels of abstraction with the phases and design steps in the design process itself (Blessing 1994). The subdividing of the design process in phases and design stages is important because the process can be structured and its complexity is broken down into easier sub-tasks. Different arrangements are made in Integral Design in order to divide the complexity of the design process in small individual design tasks that are easier and clearer:

- Product related: the levels of abstraction, for example: from system to material.
- Process related: the phases of the design process, need, purpose, function, structure, shape and solution
- Designer related: the design steps analysis, synthesizing, evaluating, implementing

The solutions for the individual tasks can be joined together via the ordering principle and eventually merged to form the solution in order to meet the need.

The transition between phases and also between the design steps provides decision points for review and evaluation of the results that are made until these design phases or steps are satisfied. A step is a design action defined as a subdivision of the design process related to the individual problem solution process of the designer, instead of it being related to the condition of the product that is under development, as indicated by the design phases.

The framework of the phases of the Methodical Design process and the pattern of the steps may be combined to form a matrix, the design matrix. This micro planning of the basic design process is the basis for the Integral Design process matrix shown in Figure 6 after Blessing (1994). Further elaboration and breakdown of the steps of the design process based on the abstraction level of technical systems led to the Integral Design process matrix.

Abstraction level		Design steps				
		Issue	Define/analyse	Generate/synthesise	Evaluate/select	Implement/shape
Problem definition	Need	Need	Make inventory of needs, goals etc.	Describe and note problem areas, needs and goals	Select problems and needs	Task/mission
	Techn. system	Design task	Analyse needs, demands, control points	Define structure of program requirements	Define program requirements	Design specification
Functional design	Sub system	Functional specification	Define and analyse the needed functions	Combine functions into function blocks	Choose the best block diagram	Function structure
	Composite tool	Physical solutions	Analyse the total function structure	Make overview of possible physical processes, categorize importance	Choose the best functioning principle	Principle decision process
Conceptual design	Tool	Modular structure	Consider proposed process	Think about possible function structures. Combine and vary function structures	Choose the best combination	Modular structure defined
	Module	Prototype structure	Analyse sketch design of chosen structure	Vary details in design	Select a layout	Provisional layout
Detailed design	Component	Technical aspects	Analyse layout	Design various forms, vary these forms	Choose the best form	Final design
	Part	Material properties	Analyse needed material properties	List of qualifying materials, make calculation	Choose suitable material	Make product documents
			Analysis	Proposal	Decisions	Solution

Figure 6. The methodology-systematic matrix of the methodical design

The Integral Design process, as well as Methodical Design process, consists of a double-cycle, as shown in Figure 7, related to the levels of abstraction, in which all the phases and steps are repeated for each element of the design product (Blessing 1994). The process can be seen as a series of activities/design steps with decision moments in which the designers must take the decision to continue or to return to a previous step in the process (iteration), see Figure 8. The designer constantly reconsiders his earlier decisions on the basis of the latest information and insights. Through the iteration cycle of interpretation-generating-decision steps in the design process, the program requirements are continuously more refined and detailed.

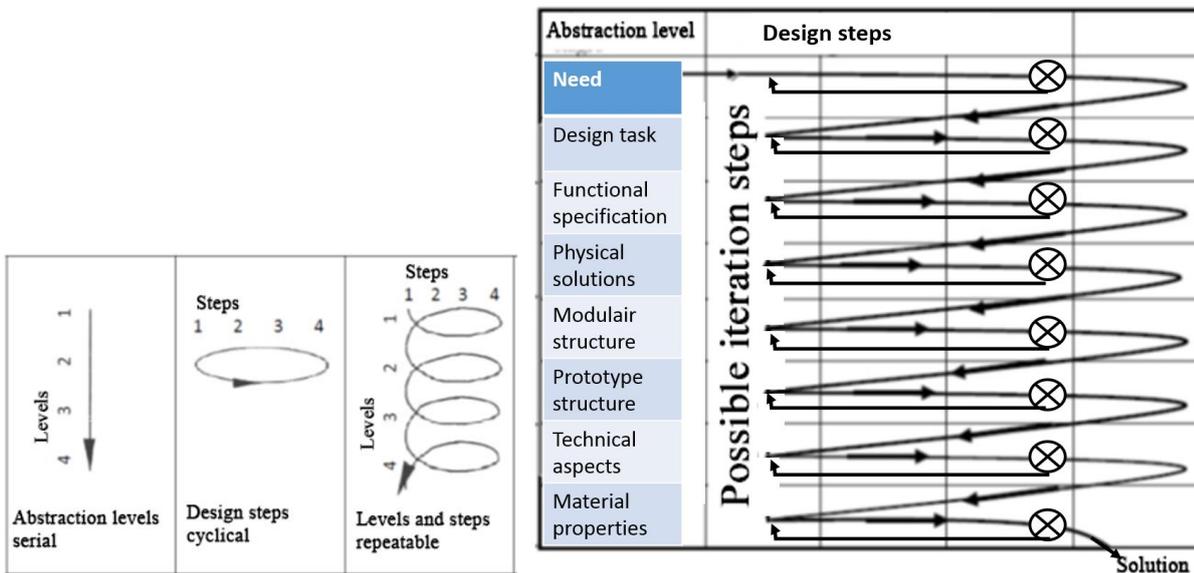


Figure 7. Main flow design process models (Blessing 1994) and Figure 8. Representation iterative process of design steps with regard to various product targeted levels in the methodical design matrix

## 5 DISCUSSION

Even though a design method is based on a complete framework with a proposed phase classification and level classification, yet there must be plenty of opportunities to deviate from this. The process

does not have to and does not normally occur, of course, step by step, but will be a dynamic interactive process, in which the designer time after time decide to skip steps at certain levels and/or skip phases. Whatever a designer does he can always place this into the general framework of the methodical design method. This makes it easier for him to keep track of what he already did and has not done. Through the description of the design process, the designer will be able to determine how far he has deviated from the theoretical pattern of the methodical design. The methodology frame work of methodical design can help to see again the correlation with the design task. Therefore, methodically design should not be seen as a compulsive step-by-step process that moves from level to level, but as a framework that helps to organize the design process and offers possible steps to take. When designing, a method can help to organize the process, making it easy to go from the general design task to specific details and vice versa. Overview can be maintained with the help of the structure of the method, a four-phase model divided into steps which distinguishes different abstract levels from system down to material specification if necessary.

In the Netherlands in several bachelor and master educational programs at Technical High schools and the University of Technology Eindhoven use this model to teach students design. As such it is the one of the more popular design method in the Netherlands. The method is also applied by major mechanical engineering companies in the Netherlands such as DAF and van der Lande Industries (Verheijden 2008).

Design can be considered a problem solving activity involving the transformation of needs to a design problem and its solutions co-evolve. Fully accepted methods do not yet exist for design (Atkinson & Oppenheimer 2016), but new process design methods should at least fulfil the old requirements as already mentioned by Cross and Rosenburg (1992):

- inquisitive: seeking to acquire new knowledge;
- informed: conducted from an awareness of previous, related research;
- methodical: planned and carried out in a disciplined matter;
- communicable: generating and reporting results which are testable and accessible by others
- purposive: based on the identification of an issue or problem that is possible to and worthy of investigation

The Integral Design method fulfils these requirements. It supports 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 result in combined efforts to further improve the design within the design process.

## 6 CONCLUSIONS

Based on an old design and well established Dutch design method, Methodical design, a new design approach, Integral Design, was developed to support all disciplines involved in building design by structuring the design process in steps and phases. The method enables, within the conceptual phase of the building design process, a structured approach at the start of the building design process. Especially the explicitly and extensively step by step approach combined with the abstract functional defined levels forming the design matrix is a new extension to existing knowledge e.g. the more basic frame work of Systematic Approach based on Pahl and Beitz (2007). All the requirements of the design task become so more transparent to all designers from different disciplines and they become more a design team with a common goal.

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