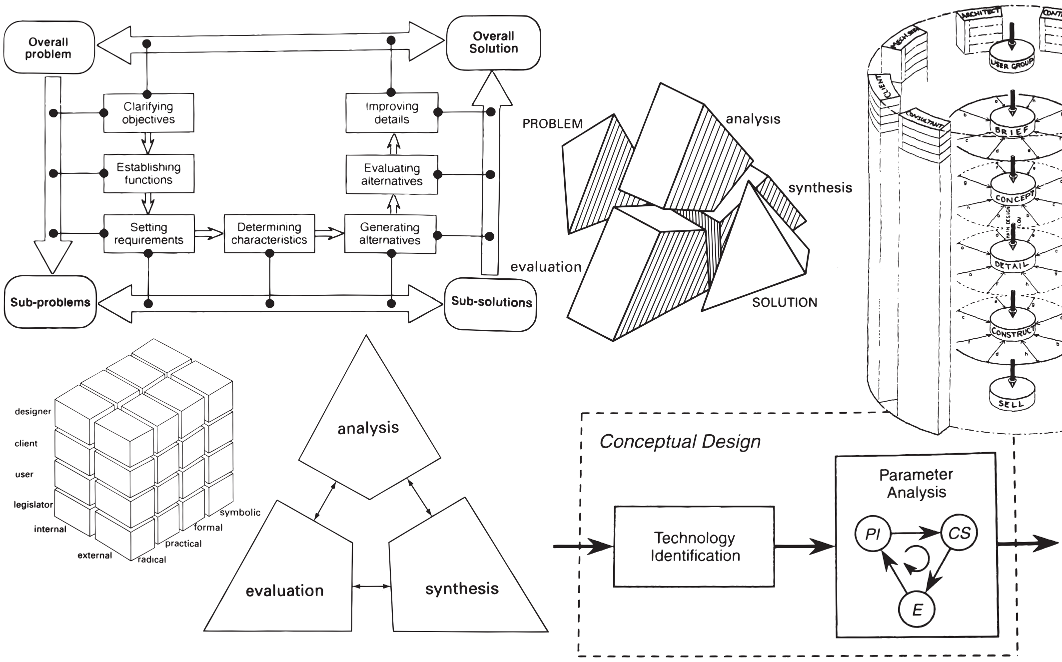


# A comparative study of theoretical approaches describing the design process for structural engineers and architects

*Master of Science Thesis in the Master's Programme Structural Engineering and Building Technology*

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CAROLINE MARTINSSON

Department of Civil and Environmental Engineering
*Division of Structural Engineering and Building Technology*
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2014
Master's Thesis 2014:2

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Cover:
Different design approaches. Top left to right: Cross (1991); Lawson (2006); Pugh (1986). Bottom left to right: Lawson (2006); Lawson (2006); Kroll et al. (2001).

Reproservice / Department of Civil and Environmental Engineering Göteborg, Sweden

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ABSTRACT

Within the building process, a design process takes place in which a design problem is analysed and possible design solutions are generated and evaluated. A well-structured and suitable design approach is of importance in order for the process to be efficient and successful. The process can be complex due to the interactions of the two design professions, structural engineers and architects, and their use of different design approaches in their work.

This thesis describes different components and features in theoretical design approaches intended for engineers and architects. The approaches are compared in order to find similarities and differences between them. The approaches are divided into four categories depending on the authors' professions and whom their approach is aimed at, and described in different scales: general view, main features and activities.

The overall similarities found between the two professions are their main phases that seem to contain the same features, and these are summarized into Analysis, Synthesis and Evaluation in this thesis.

The overall differences found are firstly the focus in the description of the approaches, either describing a step-wise method or a phenomenon with general guidelines. Also, differences are found in the structure, being either linear and sequential or more spiral and cyclical. Lastly, the suggested activities also vary.

Some of these differences are obvious due to the two professions having different expertise, background, tasks, education and goals. The risk with using different design approached may cause complications in the cooperation between them. To avoid some possible complications, improvements are suggested that include an increased understanding for the other professions approach, knowledge and background.

Key words: design process, design approaches, structural engineers, architects

En jämförande studie som beskriver teoretiska strategier inom designprocessen för ingenjörer och arkitekter
Examensarbete inom *Structural Engineering and Building Technology*
MALIN LANDH, CAROLINE MARTINSSON
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SAMMANFATTNING

Inom byggprocessen utförs en designprocess där ett design problem analyseras och möjliga lösningar genereras och utvärderas. En välstrukturerad och passande design strategi är av vikt för att processen ska vara effektiv och framgångsrik. Processen kan vara komplicerad på grund av samspelet mellan de två designyrkena, ingenjörer och arkitekter, samt deras användning av olika design metoder i sitt arbete.

Detta examensarbete beskriver olika komponenter och drag i teoretiska designstrategier avsedda för ingenjörer och arkitekter. Dessa strategier jämförs för att hitta likheter och skillnader mellan dem. Strategierna är indelade i fyra kategorier beroende på författarnas yrke samt deras målgrupp, och beskrivs i olika skalor: övergripande åsikt, huvudsakliga drag samt aktiviteter.

De likheter som finns mellan de två yrkenas strategier är deras huvudfaser som verkar innehålla samma drag, och dessa sammanfattas i faserna Analys, Syntes och Utvärdering i detta arbete.

En skillnad som finns är fokus i beskrivningen av de olika strategierna, antingen uttrycks en stegvis metod eller ett fenomen med allmänna riktlinjer. Det finns även skillnader i strukturen, som antingen är linjär och sekventiell eller spiralformad och cyklisk. Även de föreslagna aktiviteterna varierar.

En del av dessa skillnader är uppenbara då de två yrkena har olika kompetens, bakgrund, arbetsuppgifter, utbildning samt mål. Risken med att använda olika designstrategier kan dock orsaka komplikationer i samarbetet mellan ingenjörerna och arkitekterna. För att undvika några av de möjliga komplikationerna, föreslås förbättringar som innefattar en ökad förståelse för det andra yrkets strategi, kunskap och bakgrund.

Nyckelord: designprocess, designstrategi, beräkningsingenjörer, arkitekter

# Contents

# Preface

This Master's Thesis comprises 30 credits and has been executed during the fall term of 2013. The work has been carried out at Chalmers University of Technology at the Department of Civil and Environmental Engineering.

Main supervisor and examinator has been Rasmus Rempling, Assistant Professor at the Divison of Structural Engineering at Chalmers. In addition Mario Plos, Associate Professor and Head of Division at the Division of Structural Engineering, has assisted the work.

# Acknowledgements

First we like to thank Rasmus Rempling and Mario Plos for assisting and guiding us through the process.

We would also like to thank Claes Caldenby and Magnus Person, who have helped us finding relevant literature on the subject.

Gothenburg Sweden in January 2014

Malin Landh and Caroline Martinsson

# 1 Introduction

## 1.1 Background

Within the building process, a design process takes place in which the design problem is analysed and possible design solutions are generated and evaluated.

A well-structured and suitable design approach is of importance in order to have an efficient and successful design process for a building project. The process can be very complex, especially if considering the different design professions and their interactions. The two main professions, structural engineers and architects, have different backgrounds, approaches and goals that may not always agree with the other profession, and thereby creates misunderstandings in the design process. With the increasing demands for an effective building process as well as the buildings today become more and more complex, the necessity for the teamwork to function over the professional boarders is of importance.

There is a lot to gain if the design process is well structured and appropriate for the specific case, especially with the increasing demands for an effective building process as well as the buildings today become more and more complex. By having a well functional design process, the client's request and wishes can be met in a satisfactory way and both money and time can be saved. As seen in Figure 1.2 the further into the design process the less you can affect the result while at the same time more resources are needed. Therefore it is worth to have a clear design process since the decisions made will affect the entire lifecycle of the building.

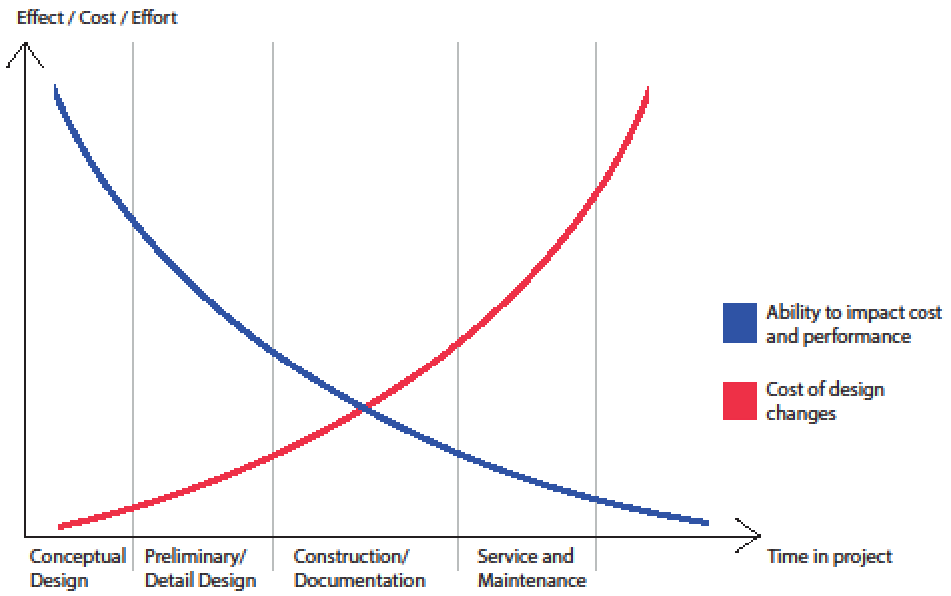



*Figure 1.1 Based on Adam Strafaci's graph (2008)*

To be able to improve the cooperation and the process, one first needs to understand how the situation is today for the two professions as well as the background to their different approaches.

## 1.2 Purpose and aim

The purpose of this investigation is to study different design approaches used by structural engineers and architects in a design process and to analyse and compare them in order to find similarities or differences that may affect the cooperation between the two professions in the design process.

The study aims at describing the components of different theoretical approaches found in literature intended for structural engineers and architects and describing their features, thereafter compare and analyse the two professions approaches.

## 1.3 Scientific approach

The work started with literature studies in order to obtain the necessary background information about the different approaches describing the design process. In order to find substantial literature and sources for the subject, teachers have been interviewed and old master theses, books and scientific articles within the subject has been studied as well as their references.

From the literature studies, information was received both about the general view of the design process as well as suggested approaches and activities. From the information found, an appropriate way of structuring the different chapters in this thesis was developed. Further, since the studied approaches vary in descriptions, a system for how to portray them in the different chapters was developed, in order to describe them in the same manner without altering their contents too much.

By also studying the different authors and sources that handles the subject, a deeper understanding of the topic was found that also gave rise to a division of the different authors.

The different approaches, activities and opinions found in the literature was summarized, both for the structural engineers and for the architects, and the different approaches' similarities and differences was compared.

Lastly, the conclusions were summarized, giving suggestions on how to improve the cooperation between the two professions in the design processes.

## 1.4 Limitations

The study will only focus on the structural engineers' and the architects' approaches in the design process, and will only focus on the initial phases in a building design process, not the more detailed phases or construction and maintenance.

This study is based on literature about design theory and does not take into consideration how the practitioners work in reality. Neither does it take all available literature into consideration, only the chosen literature for this thesis. The choice of studied design approaches was based partly on authors frequently mentioned in the design theory as well as recommendations from teachers at Chalmers.

## 1.5 Structure of the report

The purpose of this master thesis is to investigate the differences in engineering and architectural approaches in the design process. Differences between the professions will be searched for in different scales, as represented by Figure 1.2. The figure shows how the thesis will be structured by starting from a wider perspective to go more and more into detail.

Chapter 2 describes the history of design theory as well as discuss available sources and **authors** within the subject.

Chapter 3 discusses the different authors **general view** on what the design process is, what it should contain and what it should result in.

Chapter 4 handles the **main features** of the different approaches describing the design process.

Chapter 5 studies the different **activities** performed within the different approaches.

Chapter 6 contains a summary of the comparisons and discussions carried out in previous chapters. Possible improvements in the joined design process are also suggested.

Chapter 7 concludes the thesis.

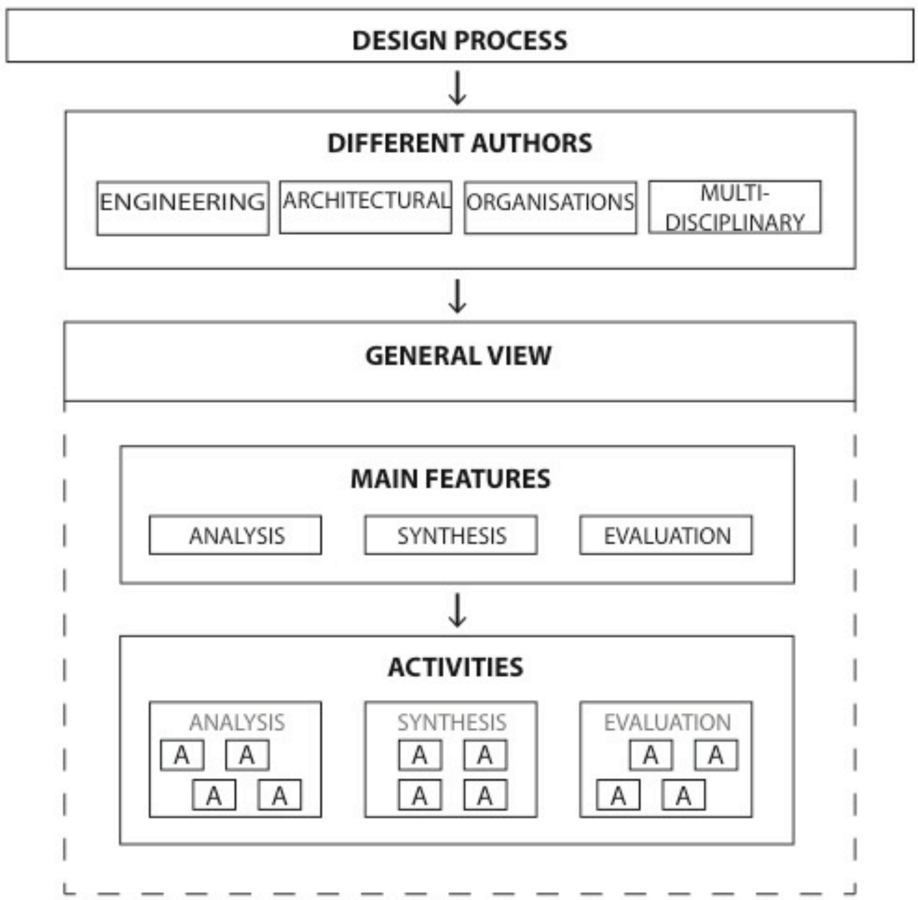



*Figure 1.2 The structure of the thesis*

# 2 Design theory and its sources

In order to understand the available approaches describing the design process today, it is important to know the history of the subject as well as the different types of authors and their background. Therefore, design theory and its authors will be described in this chapter.

## 2.1 History of the design process

### 2.1.1 The two professions

Structural engineers and architects work together and depend on each other in the building industry but are two very different. It is therefore of importance to be aware of the professions diverging expertise and background.

According to Peter Rice (1994), from his book *An Engineer Imagines*, the architect has a more creative, emotional and personal response to the client, situation and site, while the engineer's contribution is more inventive.

*The architect, like the artist, is motivated by personal considerations whereas the engineer is essentially seeking to transform the problem into one where the essential properties of structure, material or some other impersonal element are being expressed. This distinction between creation and invention is the key to understanding the difference between the engineer and the architect, and how they can both work on the same project but contribute in different ways.*

Rice, 1994

*The Architect*

The architect is a person that is trained to plan, design, and oversee the construction of buildings from an aesthetical as well as functional point of view. The main goal for the profession is to with drawings, perspectives and models create buildings, their surroundings and interior (Linn, 2013).

*The Engineer*

The engineer designs, builds, or maintains engines, machines, or as in this case structures. It is a person that is theoretical as well as practical educated in technical questions. Structural engineering is a field within engineering that analyse and design structures that support and resist loads (Oxford Dictionaries, 2013).

*Changing roles*

There have always been architects and structural engineers, however, their role in the building process have changed during the last centuries.

The history of structural engineers dates back to the Egyptians and Imhotep, who was the first known structural engineer in history. He, like other early known structural engineers such as Leonardo da Vinci, was educated in several different fields and thereby mastered both engineering and architecture. It was not until the 17th and 18th century that the foundation for beam theory and calculus was laid, which modern structural engineering is based upon (Kirby et al., 1990). Since then the engineering has developed and improved, new fields such as sustainability, climate systems etc. have arisen and new tools in computer-aided engineering has given the profession new possibilities. This increasing knowledge within the subject has thereby made it difficult for one person to master the whole building process.

The change of the structural engineering has subsequently chanced the architect's role. Before the mid-1900s the architects had more understanding in technology, mechanics of materials and geometry, but when the knowledge in engineering and building technology increased, the architect's possibilities to possess all the understanding of the subject eventually became unfeasible. In Sweden, the final decision that changed the architect's role was taken in the early 1900s when the government decided to make the architectural education more artistic (Lundin, 2012).

Due to the architects and engineers roles now being more separated, the need for a well-functioning collaboration and understanding of each other's knowledge is essential to the building process to be able to succeed.

*Multidisciplinary Design*

A response to the increasing complexity of buildings today and the need for close collaborations, multidisciplinary design has been introduced. Ove Arup, considered as one of the leading architectural structural engineers of his time, introduced what he refers to as Total Architecture, as an aim for his firm in the 1970s.

*"Total architecture" implies that all relevant design decisions have been considered together and have been integrated into a whole by a well-organised team empowered to fix priorities.*

Ove Arup, 1970

The idea with multidisciplinary design is that designing is not a individual performance, it is a team effort, meaning that all design and engineering disciplines should be involved in the designing from the start (Addis, 2007).

### 2.1.2 Design theory

Design theory and the understanding of design ability started in the early 1960s for both professions, and since then many attempts have been made to describe the design process. The first generation of descriptions was mainly influenced by theory of technical systems, and these theories created an image of designing as a rational process. However, these models received criticism, and a need to describe the process more in detail emerged, giving more focus to the processes and its activities. (Dorst et al., 1995)

Early models of the design process for engineering design were probably based on a pioneering research paper by Marples in 1960 who studied engineering designers. The early architectural models of the design process were very similar to the engineering models at this time. However, in the early 1970s these shared models were criticised by architectural design methodologist leading to a change in the architectural models.

Since then the engineer's and the architect's way of describing the design process has been separated, and today there appear to be significant differences between them. In the future, there are many good reasons to try to make the two models converge again (Roozenburg et al., 1991).

## 2.2 Literature about the design process

By studying the available sources within a subject, a further understanding of the subject and its background can be found. The amount of sources, the content and its structure, as well as the various authors can describe more about the subjects' popularity, age, general perception, and complexity.

*Available sources*

Through searches on the topic design process, there seem to be a lack of described approaches within the area. The sources found varied in both content and structure. Further, very few descriptions of design process are available for structural engineers and many sources seem to be based mainly on product and industrial design processes. For architects, there seem to be more sources available, however, they appear to be more vague and do not describe an approach, they rather describe the design process as a phenomenon. A lot of sources also describe what should be performed, but not how.

The lack of available sources may be that designing is very different from conventional problem solving and requires another type of perception, which is probably the reason why it can be so difficult for designers to explain and discuss their ideas (Lawson, 2006). Further, it may also depend on the notion that when such a description of an approach appears, it is quickly criticised or disputed and therefore never accepted as a general model (Pugh, 1986).

Another aspect that makes the design process difficult to explain is that the term design process is very wide and undefined. Today the word design is used for several different fields and professions. Due to the subjects' wide perspective, the study connected to it is performed within a loosely defined international network of researchers and practitioners from several different fields, for example architects, engineers, industrial designers, mechanical designers etc. Design theory is therefore based on many different aspects and opinions from researchers within separate fields within design, which may lead to the design process being versatile in its description (Lundequist, 1998).

Worth keeping in mind is that the theory and research about how design is performed is relatively new, in comparison to how long the human beings have been designing. Many studies instead focus on the resulting buildings and products, not the process itself, not until recent years that is (Cuff, 1998).

*Different authors and categories of descriptions*

For the sources found there are various ways to explain the design process: step-wise maps, words describing it as a phenomenon, lists of what should be done considering rules and regulations, descriptions of already executed processes etc.

Similar to the various ways to clarify the design process, there are various authors describing it. Since the subject is diffuse and there is no right and wrong, every author has their own take on the design process and how it is performed. It is therefore important as a reader to be aware of both what category the description belongs to, as well as whom the author is and his intentions, to know the descriptions limitations.

Many of the authors are often people that have theoretically studied and thought about design, not the practising designers themselves. One should then keep in mind that these authors might then actually have no insight in how to design in reality and that their approach may only be theoretical (Lawson, 2006). Some of these authors are teachers, striving towards creating educational material to ease the students learning.

Descriptions of how a process was performed, or how a designer worked in reality, can be described by the designers themselves, writing about their own process and what they thought have or has to happen. Since these are based on the person´s own thoughts, there is a risk it might not be perceived right, neither by the writer himself nor the reader (Lawson, 2006). Further, if the described designer is well established and if he has a special style or focus, a different view on the design process may be given compared to the everyday designer. This will be mirrored in the types of projects, the team members assisting the process, the assigned budget and time schedule, as well as the designers' more or less free reign on the design decision.

The descriptions can also be by an author describing another designer work based on either observations or interviews. However, Lawson believes that observations can be misleading since much of the design process happens inside the designers mind and cannot always be seen. Also interviews can be misrepresentative since it can be difficult to actually trust what the designer says. The designers may give a false impression of their mind process, simply because they do not know exactly what happens themselves or do not wish to risk revealing their weaknesses (Lawson, 2006).

As described, there are various descriptions of the design process written by several different authors. It is therefore of important to keep in mind who the author behind the described approach is and their intentions with it.

*Approaches may differ from reality*

As described, there are different limitations with different categories of descriptions and the authors will angle the description to their own beliefs and interests. However, one need to keep in mind that no proof or writings exist that the designers actually follows the descriptions (Lawson, 2006). This was discovered by L.L. Bucciarelli, who observed the design work within an engineer firm for two years, and found that the design work as it proceeded did not correspond with the theoretical approaches (Bucciarelli, 1984). Most practitioners use a less defined route, one that more comes from their own interests, approaches and strategies. There is not one clear method for the design process, but rather several different possible methods (Lawson, 2006). Björn Linn continues, in the journal *Arkitektur som kunskap*:

*We only know that the formulations never will be complete, in the same way as a model of the reality never actually is.*

Linn, 1998

## 2.3 Discussion

*Available sources*

From searches of literature describing the design process, there seem to be a lack of sources presenting approaches. This may depend on different factors such as design theory being a relatively young subject and that the term design is very wide and undefined. It may also depend on the nature of design problems, that they can be very abstract and therefore it is hard to describe them in words. However, Hörngren writes in her article *Medvetandegörande ord* that in order to improve the design process, the designer needs to be aware of what process they use today (Hörngren, 2008)

*Different authors and descriptions*

From the literature, there are both different ways to describe the design process and various authors describing it. Due to this, one needs to be aware of how these two factors will affect the described approach. For natural reason, engineering authors seem more prone to describing the design process from a more technical and theoretical point of view and many books are directed towards students for educational purposes. In addition, the engineering approaches are mainly directed towards product design and approaches intended for structural engineers seem to be missing. Architectural literature on the other hand seem to write about well-established architects' projects and processes or write about the design process after observations or interviews with designers.

*Sources used for education at Chalmers*

Already in the early stages of the education, the use of literature regarding the design process varies between the two professions.

At Chalmers, it seems that the descriptions of the design process used for structural engineers in educational purposes are directed towards industrial and mechanical design, such as Kroll et al. and Pahl et al.'s approaches. There may be a risk with using methods aimed towards product design in building design, since they may not be fully compatible. Neither do they describe the cooperation with the architects.

At the architectural department at Chalmers, no step-wise approaches are followed or used in educational purposes. Architects are encouraged to find their own approach to design, and literature that is recommended to the students describe design in more general terms, giving guidelines and recommendations. Architecture students also seem more prone to find inspiration from well-established architects and their processes, which can be risky since these projects often do not portray an "everyday" project. Similar to the engineering student, the architect students do not receive any training in how the collaborative process should be carried out.

The differences in use of literature may affect the respective view on the design process and their future collaborations between the professions.

*Collaboration*

It appears as if the engineering authors and the architectural authors most often describe the design process in two different ways. There may be several reasons for this difference in descriptions, however, there may be a risk that these differences in descriptions will affect the view on the design process and therefore complicate a joined design process.

Another interesting aspect is that most descriptions, both architectural and engineering, seem to be aimed at a single designer instead of describing a design team's process, which is how it is usually performed in reality. Two approaches that do mention the collaborative side to the design process is the architectural organisation RIBA and Cross. RIBA's approach is in one way based on the different professions in the design process and their collaboration, however, it do not describe how the collaboration can be performed when designing. Cross aims at describing an approached that can be used by both professions, but neither he does describe how the collaboration should work. He believes that by having the same approach for the design process the collaboration in the design process will be easier.

Since both professions work as designers in the same project, a common approach with shared terms could be beneficial for the collaboration.

# 3 General view on approaches in the design process

Design process and conceptual design are two words commonly used even though the words are very abstract and their meaning rather undefined. This chapter depicts what the general thoughts on what an approach that describes the design process is and should contain, from both the engineer and architects point of view. By studying the author's different views of the design process, the background for how their approaches are built up can be found.

## 3.1 How approaches are described

*The existence of a method*

One dilemma that dominates the views on the design process is whether a step-wise method should exist or not. This is apparent through the literature studies on the subject, and as stated in Chapter 2.2, some authors describe a step-wise method while some rather try to describe a phenomenon.

From the literature search, the engineer authors seem more prone to use their books to suggest a step-wise method for how the design process can be performed. The engineering authors Pahl et al. believe that in order for a design to be successful, the required design activities must be structured in a fixed way, creating a clear sequence of different phases and steps. Therefore they describe an ordered and stepwise approach, in an attempt to rationalize the design process. Their aim is to create a general working procedure, which would help the designer to handle the complexity of the design process. This way of working in a step-wise manner will help to plan and control the flow of work (Pahl et al., 2007)

Pugh, also an engineer, similarly to Pahl et al. believes that a structured approach to design is necessary in order for the user-need situation to be satisfied. By using graphic models or maps of the design process, the understanding of the different activities will greatly increase. However, Pugh emphasises that such a structure should, whilst presenting a systematic way of working, also allow for variations (Pugh, 1986).

Further, the engineers Kroll et al. have a similar view of the design process, however they are more cautious to use the word method. Instead they define it as a methodology that should lead the user through the design process. Their methodology consists of several different steps, all thoroughly described, where innovation is emphasized throughout the approach (Kroll et al., 2001). Although Kroll et al. calls this a methodology, their approach is very predefined and the structure is very similar to Pahl et al. and Pugh's stepwise-method.

In contrast to the authors describing the engineer's process, the architect and psychologist Lawson claims there is not one clear method for the design process, but rather several different possible methods. Even though several maps exist prescribing how the design process works, many practitioners use a less defined route, one that more comes from their own interests, approaches and strategies. Inevitably, everyone will understand and approach design based on our own particular background, and different professions will define design in different ways. The design process is too complicated to be described by a single diagram since it is a very personal and multi-dimension process (Lawson, 2006).

This was discovered by the architect student from Chalmers, Cecilia Hörngren, who wrote an article in the journal *Kritik* (2008) about her search for an understanding of the design process. During her research she found no architectural methods describing the design process, and she experienced a fear among architects for using the term method. She believes the term "method" is seen as a specific way to work where every activity is done in a step-wise manner according to a given list, and by working according to a predefined approach their creativity and personal style will be restricted. She believes that the designer should be provided with notions of the design process, not a method (Hörngren, 2008).

The architect's fear to write down a method can further be seen in the works of Lawson, Cuff and Lundequist. Their intention is to write about the design process and to clarify it, however, no method is ever mentioned. Lawson instead lists some of the important features of design thinking and describes abilities that a designer needs to have (Lawson, 2006). In a similar manner, Cuff portrays the design process as a series of dialectics, which can be seen more as guidelines on how to design a successful building (Cuff, 1998).

Another way to perceive the design process is described by Lundequist who describes the context and how the design is only an addition to something already existing. He describes the new design as ΔA while the context is A. The addition ΔA need to be adapted to the site, the function as well as the social, political and cultural context (Lundequist, 1998).

Cross, who represents the multidisciplinary authors, has a mixed view on the design process. He believes that design methods are not the enemy of creativity, imagination and intuition. Instead, if executed properly, a design method will guide the designer to create novel design solutions and aid creativity. Cross believes that a model should integrate both the engineering and the architectural visions to be appropriate. The model should be descriptive in order for the designer to know what activities should be done, but is should not only focus on the technical aspects of designing, it also needs to portray the cognitive processes that take place. He also emphasises that a clear and well-organised approach can be very favourable in the design process. However, there is a risk of these models becoming too formalized and too structured. Therefor methods need to have two principal features: to describe and formalize certain processes in designing as well as express features of design thinking (Cross, 2000).

As described, engineers and architects seem to have different opinions on whether a step-wise method of the design process should exist or not, engineers appear to believe in linear methods while architects do not. However, the organisations studied in this thesis, both the architectural organisation RIBA and the engineering organisation FIB, seem to not take sides in this matter. They describe the process with different steps, yet they mainly describe what should be produced, not how.

*Different types of tasks*

The differences in opinion concerning if a prescribed method should exist or not may originate in the two professions different types of work tasks. Therefore, certain approaches may be more appropriate in some situations than other. Rational descriptions are especially apt when the design problem is fairly clear-cut, in which the designer can follow certain described activities. When the design problem is unclear, the designer will have no standard strategies to use, and a more reflective process can be useful. (Dorst et al., 1995)

Similarly, Lawson believes that if the problem is precisely stated, a designer could be able to use a step-wise approach. However, his opinion as an architect is that design problems are often are a bit unclear and ill defined, and therefore a step-wise method cannot be used (Lawson, 2006). In agreement, Roozenburg et al. claims that architects mainly do view design problems as ill-defined, however, they also state that engineers view them as well-defined (Roozenburg et al., 1991), and maybe this is one of the reasons engineers are more positive to the use of a step-wise method than the architects.

Further, Lawson gives a caricature of the engineer and the architect: the engineers design process is thought to be more precise, systematic and mechanical, while the architect can be said to be more imaginative, unpredictable and spontaneous. What is required as a result from the engineers design process can maybe seem more clear, for example if designing a beam, the design should result in a beam that is able to span the required length and carry the known loads. While the architects goals can be more vague, designing a beautiful façade or plan a well-functioning apartment. However, keep in mind this being to some extent caricatures of the two professions. Good engineering will require imagination and can also be unpredictable, and good architectural design is unlikely to be accomplished without technical knowledge (Lawson, 2006).

According to David Allen, the author of *Getting Things Done* (2008) that describes the Natural Planning Model that aims to help people planning everyday tasks. Different tasks are solved differently even though they all can, according to Allen, follow a basic five-stage method (Allen, 2008). Maybe the building industry works similar to the everyday life, such that the approaches used will vary due to the task and its performer.

*Other possible reasons*

Another reason for the difference in opinion between the two professions may be that the knowledge domains for the two professions are different. Engineers can rely on science, while architects lack the equivalent science and that makes them having to trust more in trial and error (Roozenburg et al., 1991). Further, since engineering relies on science, they may adopt scientific methods for designing which usually are more step-wise. Lawson continues by saying that how a design problem is perceived depends on our ideas how to solve them, which generates from the designers own experience and expertise. Designers from different fields will thereby understand the problem differently and come up with different solutions (Lawson, 2006).

These differences may also originate already in the two professions education. Engineers have a more science-based and problem-focused education while architects have a more arts-based and solution-focused education (Lawson, 2006), which is natural due to their different knowledge domain.

In an education, it is not only the subject that is being learned, the students are also introduced into a certain culture with its own attitudes and language. In the design process, communication is a very significant part of the collaboration and they need to share a common understanding of design concepts and knowledge. If not, the same word can have different meaning for different people and for different projects, for example “green” can be many different shades of green, and “a bit longer” can be very different lengths (Lawson, 2006).

## 3.2 Discussion

*Difference in usage of step-wise approaches*

There seem to be a difference between the two professions view of what an approach that describes the design process is and should contain. From the literature, the two professions seem to disagree on whether a step-wise approach should be used or not; engineers believe it exists while architects do not believe in a general predefined method.

It seems as most engineering approaches encourages a step-wise approach. A well-structured way of working will lead the designer through the design process (Kroll et al., 2001) and also help the designer to handle a design problems complexity (Pahl et al., 2007). Further, a systematic approach is necessary to understand the different activates in the process, and to make sure the user-need situation is satisfied (Pugh, 1986).

In contrast, architects appear to reject any step-wise method. Design problems are often uncertain and it is not possible to know all aspects of a design process, some aspects may arise or change during the process. Further, the problem and the solutions are emerged with each other, and it is therefore hard to describe the process as linear (Lawson, 2006). Architects also seem to have a fear of using the word method and appear to believe that step-wise methods will restrict the creativity and the personal style. Instead they try to describe the problem-solving process with attitudes and guidelines (Hörngren, 2008), which can be seen in the descriptions by Lawson, Lundequist and Cuff.

However, although the two professions may disagree on whether a step-wise method can or should be used or not, they appear to share a common opinion that it is important to be aware of your methodology.

*Reasons for these differences*

It appears as if engineers and architects do not share a common opinion of what an approach that describes the design process is and should contain. There can be many reasons for this, some of the may be:

- Different types of tasks
- Knowledge domains
- Experience and expertise
- Education
- Language

Firstly the two professions have *different types of tasks* and design problems which makes it is very likely that the two professions will work with different strategies when solving their problems and thereby their general view will also differ. In the same manner, the *knowledge domain* as well as the *experience and expertise* will affect the understanding of a design problem and consequently how it is solved. These reasons will probably always exist because structural engineers and architects are two different professions, however, what can change is their understanding for the other profession.

Another reason for differences in the general view might be the two professions *education* and how it handles the design process.

At Chalmers, design process as a phenomenon is continuously mentioned to the architectural students during their education and they are encouraged and trained to find their own design process. Structural engineering students, on the other hand, receive less education and training in designing as well as theory about the process. Some courses are offered in the subject; however, it cannot be seen as continuous subject in their education.

Further, the view on the context and how it should influence the design differs and seem to originate in the education. Architect students seem more trained in handling the context and take advantage of it in their creation, than engineering students. This can be enhanced by usage of product design literature in educational purposes, since a product have less or different focus on the context.

From their educations, engineers and architects may have developed different *languages*, which can complicate the collaboration if they do not understand each other. In addition, if different languages are used, it may be a possibility that the design process is actually described similarly, only in different words.

# 4 The different approaches of the design process

## 4.1 Main features of the approaches

This chapter describes the different author's approaches and their main features. Firstly the main features of these approaches will be described separately in Chapter 4.1 and subsequent chapters will discuss relevant aspects.

Divisions between the different approaches have been made, dividing them into engineering, architectural, organisations and multidisciplinary approaches, in order to make it more comprehensible. In Appendix A, more information about the authors is given that is the basis for the division.

### 4.1.1 Engineering approaches

Below follows main features of the approaches described from an engineering point of view.

**Kroll et al.**

***Aim***

Kroll et al.'s aim is to present an approach which is systematic but still flexible, to guide the designer through the different phases. The intent is that if the designer knows his current step in the process, as well as the following step, he will be more aware of how to take the design further into the next phase. By sub-dividing the problem into smaller phases, the design problem will be less complex and more manageable, thereby minimizing the risk of getting stuck or from a blank paper trying to solve the whole problem all at once. All through the process, Kroll emphasises innovation in all different steps and phases, and that it is supposed to be the innovation that is the driving force in the process (Kroll et al., 2001).

***Overview***

Kroll et al. describes a step-wise approach, divided into three main categories: *Preparation Phase, Conceptual Design* and *Realization*, as seen in Figure 4.1. The preparation phases consist of *Need Identification* and *Need Analysis* and the conceptual design phase consist of *Technology Identification, Parameter Analysis* and *Concept Selection*. Realization contains *Embodiment Design, Detailed Design* and *Prototyping*, however, the realization phase is not covered in detail in the book, nor in this thesis.

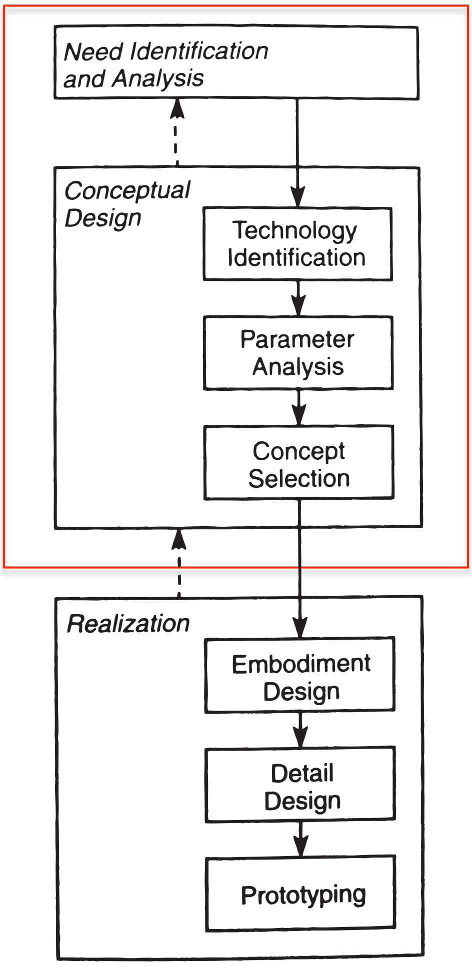



*Figure 4.1 Overview of Kroll et al.'s design process (Kroll et al., 2001)*

They describe the conceptual design phase as a continuous loop between the concept space and the configuration space, where the solution goes through realisation and abstraction, seen in Figure 4.2 (Kroll et al., 2001).

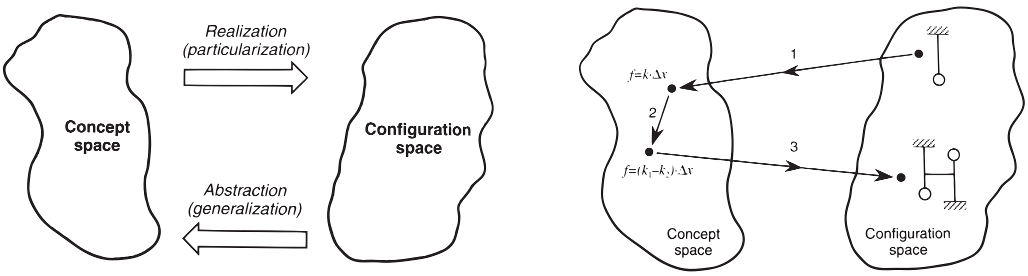



*Figure 4.2 Model of the concept and configuration space (Kroll et al., 2001)*

***The approach***

The *Preparation Phase* is divided into *Need Identification* and *Need Analysis*. *Need identification* deals with discovering the real need of the task. In the *need analysis*, the design task is analysed and studied from the five general categories: performance, value, size, safety and special. The requirements and limitations found are summarized and documented as a set of specifications, which Kroll refers to as the Design Requirements (Kroll et al., 2001).

The second phase, *conceptual design* (see Figure 4.3), consists of the three main parts: *Technology Identification, Parameter Analysis* and *Concept Selection*. *Technology Identification* is the first step in the conceptual design in which as many general technical principles and suggestions as possible should be addressed. These core ideas are the starting point for developing concepts to solve the problem at hand.

The second phase, *parameter analysis*, works as an iterative loop that goes through the three steps: *parameter identification (PI) - creative synthesis (CS) – evaluation (E).* The entire phase is centred on handling parameters.

*The word "parameter" is used to describe in a very general way any issue, factor, concept, or influence that plays an important part in developing and understanding of the problem and pointing to potential solutions.*

Kroll et al., 2001

The first step, *PI*, is about finding the main parameters of the problem. In *CS*, physical suggestions are made to accommodate the concept parameters found in the previous step, *PI*. In the last step in the loop, *E*, the designer must determine and consider how suitable and well functioning a suggestion is in relation to the entire problem (Kroll et al., 2001).

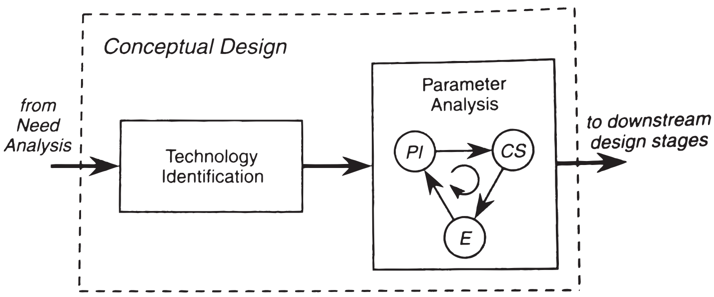



*Figure 4.3 Model of Kroll et al.'s conceptual design phase (Kroll et al., 2001)*

**Pahl et al.**

***Aim***

Pahl et al.'s aim is to describe a general working procedure that consists of a set of design activities, structured in a fixed sequence. They argue that by having a structured design process, the designer will be able to handle the complexity of the design process, and it will also help plan and control the flow of work.

Even though they advocate a clear and well-structured design process, they also emphasize the importance of intuition in the design process in order to keep focus and have the overall solution in mind. They also encourages the designer to develop an own personal working style, to have some freedom in the work to select preferred methods, the sequence in which they perform certain steps as well as the information they wish to use for the specific task (Pahl et al., 2007).

***Overview***

For their approach, Pahl et al. have divided the design process into the following phases: *Task Clarification, Conceptual Design, Embodiment Design* and *Detailed Design*, which can be seen in Figure 4.4. This study will cover the two first phases, task clarification and conceptual design.

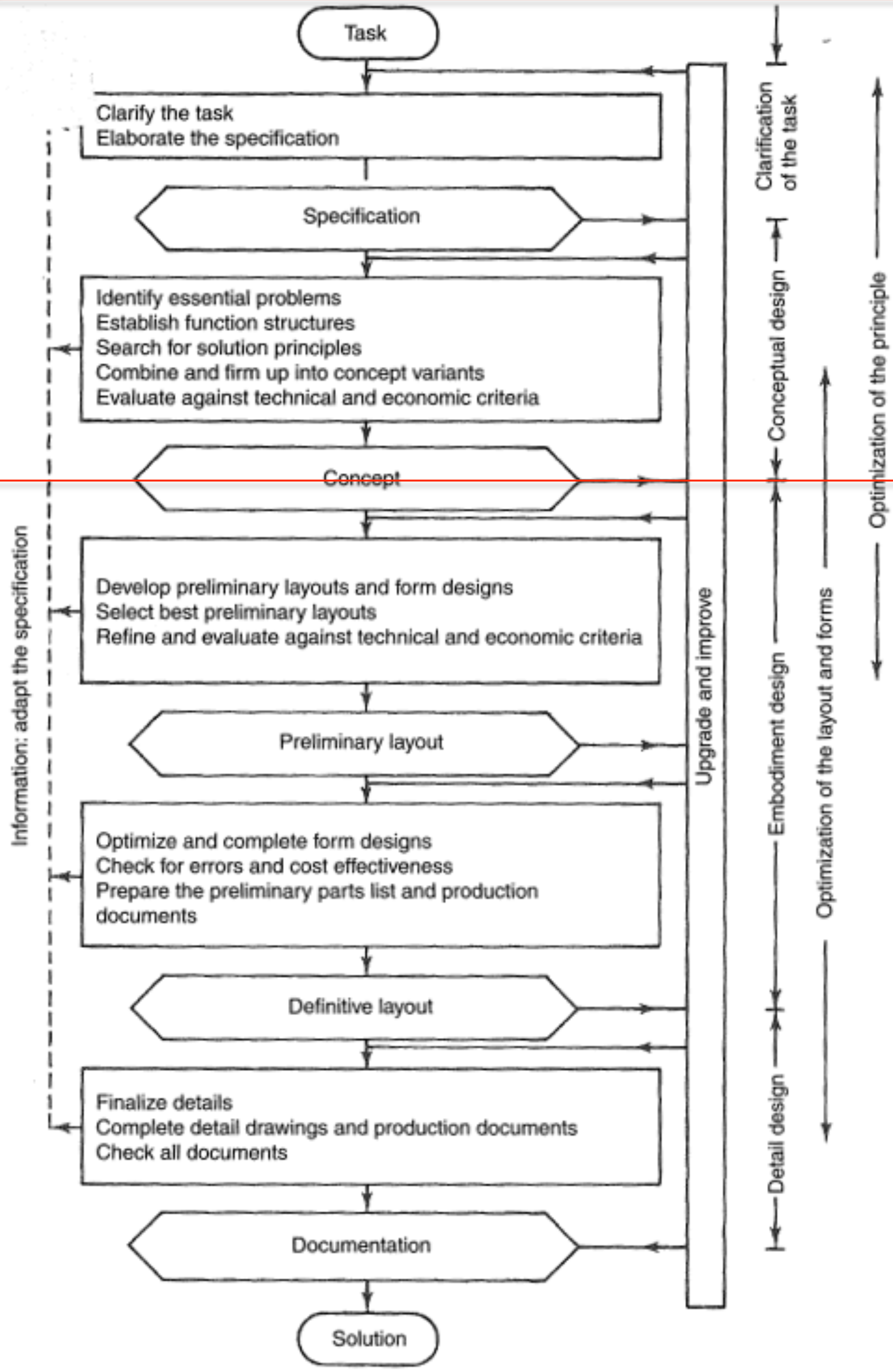



*Figure 4.4 Steps in Pahl et al.'s design process (Pahl et al., 2007)*

All phases go through the same stages: *Information, Definition, Creation, Evaluation* and *Decision.* Within these stages, different activities are performed.

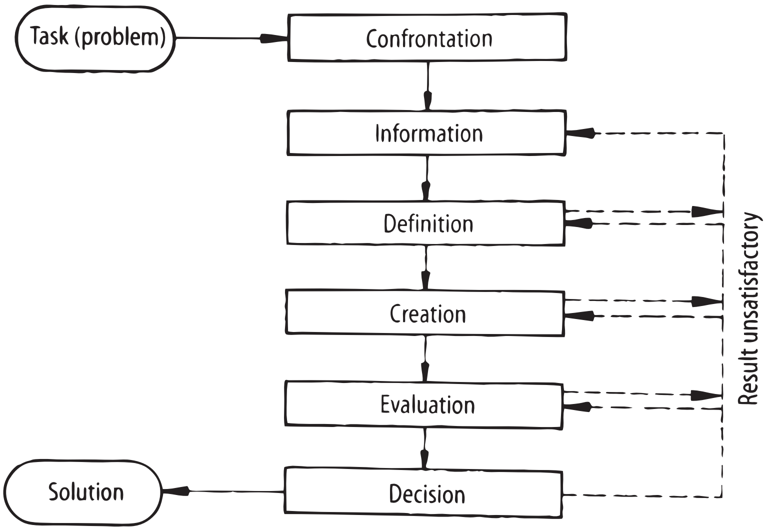



*Figure 4.5 General problem solving model (Pahl et al., 2007)*

In addition, Pahl et al. state their method is a systematic approach with the following main conditions that need to be satisfied during the process:

*Define goals.* The overall goal/goals, the sub-goals and their importance should be defined. Gives insight to the problem and motivates a solution.

*Clarify conditions.* The initial and boundary constraints should be defined.

*Dispel prejudice.* In order to be able to get a wide variety of solutions, prejudices should be dispelled.

*Search for variants.* A number of solutions or combinations of solutions should be presented to have a wide range of suggestions from which the best can be chosen.

*Evaluate.* The suggestions should be evaluated based on the goals and conditions.

*Make decisions.* Objective decisions should be made together with experience in order for progress in the process.

***The approach***

In the first phase, *the task clarification*, the general and specific requirements and constraints should be identified and formulated and a requirements list should be set up. The phase can be divided into two main steps: defining and recording the obvious requirements and refine and extend the found requirements using special methods.

The *conceptual design phase* is where a solution principle is found and elaborated. The solution principle is found by: identifying the essential problem and establishing function structures (overall function and sub-functions), generating suggestions for solutions to fulfil the sub-functions and combining these into a working solution. These combined solutions will then be evaluated so that one working solution can be chosen in the end of the conceptual design phase and taken into the embodiment design phase (Pahl et al., 2007).

## Stuart Pugh

### *Aim*

Pugh’s approach is a systematic and disciplined process, based around a core of design activities, seen in Figure 4.6. Pugh’s work is based on his theory of total design, that total design is a necessary systematic activity that involves product, process, people and organization. Therefore, in his model, Pugh strives to include both the process of the product as well as dealing with the business activity around its creation. The model creates a strict framework in which creative work is allowed. This framework will hopefully aid the designer in the work and to create complete design (Pugh, 1991).

### *Overview*

The model is divided into a core containing the product design and an outer perimeter that represents the business design. The inner core is the most central to the model, since without a product or building, there is no design process. The inner core is divided into the following steps: *User group, Brief, Concept, Detail, Construction* and *Sell.* The steps *User group, Brief,* and *Concept* will be covered in this study.

The outer perimeter incorporates the business aspects that affect the process, such as different professions, specialisms, economy, authorities etc.

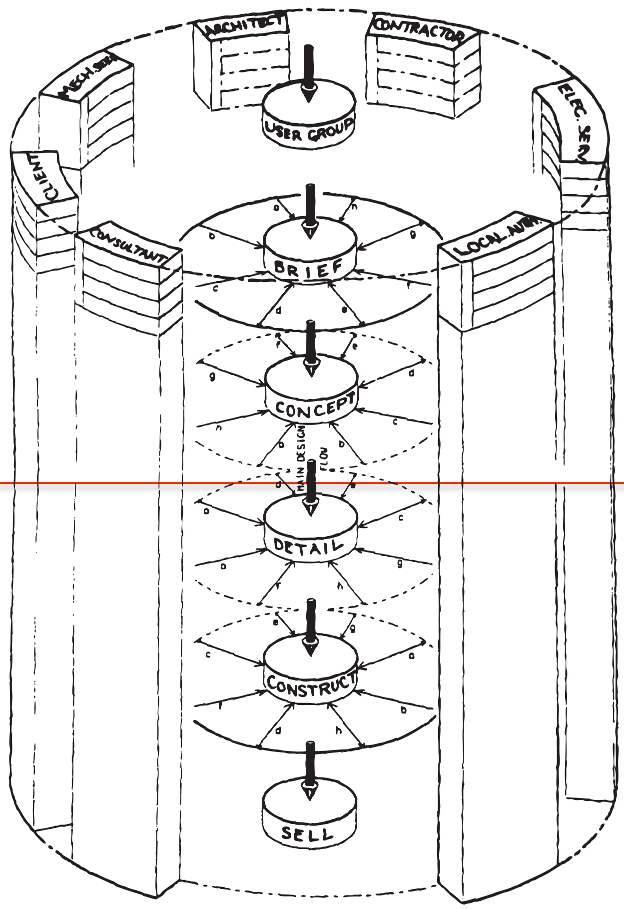



*Figure 4.6 Pugh’s total design model for the design process (Pugh, 1986)*

***The approach***

The *user group-step* includes examination of the market and user needs, which requires investigations of many aspects that is related to the project at hand. This step involves acquiring a lot of information, and also to know various analysing techniques to understand what to do with the information. The suggested analysis techniques are parametric analysis, needs analysis and matrix analysis.

The second step involves creating a project brief, a Project Design Specification (PDS). The PDS will set the requirements of the project, entails different categories such as safety, environment, maintenance, customer, time scale, performance etc.

The *concept phase* is mainly focused on generating solutions that meets the requirements and needs, i.e. the PDS. The conceptual phase can be divided into two cyclical, major components: generation of solutions to meet the need and evaluation and selection of the solution that meets the PDS the most (Pugh, 1991).

### 4.1.2 Architectural approaches

Below follows main features of the approaches described from an architectural point of view.

**Bryan Lawson**

***Aim***

Lawson strives towards creating an understanding how designers think and what techniques and abilities they use in the design process. He works towards creating a model of designing, however he always emphasises that no step-wise method can ever be found that describes the design process. Instead, he aims at describing all the different aspects of designing and designers, which he then summarises into different groups representing his view of the design process.

***Overview***

Lawson suggests that there are several different activities that take place during the design process, without a predefined order. In an attempt to structure the activities, they are put in the following groups: *Formulating, Moving, Representing, Evaluating, Reflecting* and *Bringing problems and solutions together.* These groups are what Lawson believes constitute the design process, and their features are described in the model as well as the abilities that the designer needs to have (Lawson, 2006). These groups are interpreted in Figure 4.7.

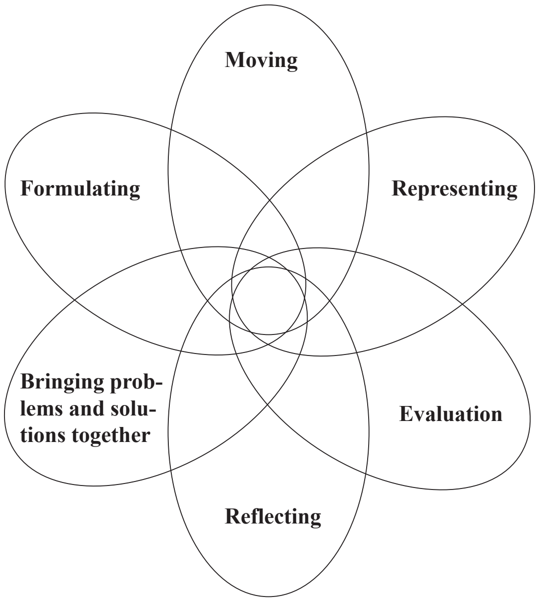



*Figure 4.7 An interpretation of Lawson's groups. Note that this is not Lawson's own figure, only an interpretation.*

***The model***

The first group is *Formulating*, how to understand and formulate a design problem. The category consists of three issues: ways of understanding the design problems, identifying and framing.

The second group is called *Moving*, and contains skills that involve making suggestions of design solutions, i.e. making moves to solve the problem. The group contains creating solution ideas, primary generators and interpretive and developmental moves.

These moves are often described in drawings, text, diagram, that represents the move, which embodies the third category: *Representing*. Representing consists of: ways of representing design situations, conversations with representations and working with multiple representations.

To regulate and select appropriate moves, skills in *Evaluation* are needed. These skills are summed up in: objective and subjective evaluations and suspending judgement.

The last group is called *Reflecting* which contains the skills that oversees the process, supports it and keeps it on the right track: reflecting in action, reflecting on action, guiding principles and collecting precedent or references.

With the help from the activities and skills in the different groups, the designers somehow seem to manage to find their way from a design problem to a design solution.

He also mentions the group *Bringing problems and solutions together*, which gives general guidelines that should be considered throughout the process. These four guidelines are: problem and solution are inseparable, no clear order of appearance, briefing is a continuous process and parallel lines of thought (Lawson, 2006).

**Jerker Lundequist**

***Aim***

Lundequist does not have a step-wise approach. Instead, he aims at giving a general overview of the design process and bases his work upon the research within the field of design theory. Lundequist defines design as an activity used to find an artefact or a system of artefacts and to shape these according to the design problems characteristics.

*An artefact is an artificial, man-made thing, product (also abstract phenomena as organisations, plans and information systems)*

Lundequist, 1998

He emphasises that designing should consider the products entire life, from creation to manufacturing and usage (Lundequist, 1998).

***Overview***

Regardless what product that should be designed, Lundequist states that there are always three different phases that every product design undergoes*: product definition, product manufacturing* and *the usage of the product.*

Within these three phases that constitutes the whole design process, there are four sub processes that describe different aspects of the task: *artistic, information handling, negotiation and decisions* and *problem solving and handling.* These aspects are described as parallel processes, within the three phases (Lundequist, 1998). An interpretation of Lundequist's approach can be seen in Figure 4.8.


*Figure 4.8 An interpretation of Lundequist's processes and sub-processes. Note that this is not Lundequist's own figure, only an interpretation.*

***Steps and sub-processes***

The three phases are divided into the following main steps:

*Product definition* which handles investigation, program description, planning, calculation, visualization etc.

*Product manufacturing* describes manufacturing and the planning of it.

*The usage of the product* deals with usage, service, maintenance and management as well as planning of these.

Within these three phases, the four sub-processes runs parallel. The first sub-process, the *artistic process,* contains the creation and designing of a constrained but meaningful entirety. The *information handling process* is in which the information relevant to the project is found, processed and distributed. In the *negotiation and decision process* different decisions concerning the product are discussed by the participants involved in the specific problem. The last process, *problem solving and handling* is a central part of the design process, and handles problems that arise in the process. (Lundequist, 1998)

## Dana Cuff

### *Aim*

Cuff neither suggests a step-wise method nor a freer approach, instead she states:

*To understand what architectural practice is all about, I have found it appropriate to apply a model that portrays the design process in practice as a series of dialectics.*

Cuff, 1991

Cuff's aim is to fill the gap she believes exists in most management literature, and to increase the understanding of the architectural practice. She wishes to describe the dynamics, fluctuations, complexities and uncertainties that characterize the architectural practice and its everyday life. With this knowledge and understanding, she hopes to encourage excellence and development of outstanding buildings (Cuff, 1998).

### *Overview*

From her studies, Cuff believes there is a set of contradictory forces that structures the design process. These contradictory forces will create a dilemma to the designer, who will attempt to solve these dilemmas with the help of mixed strategies, i.e. dialectics. These dialectics are:

1. *Quality demands*
2. *Simplicity within complexity*
3. *Stereovision*
4. *Open boundaries*
5. *Flexibility with integrity*
6. *Teamwork with independence*
7. *Exceeding the limits*

Their order depicts their likely appearance in the design process of a successful building (Cuff, 1998).

### *The dialectics*

The first 4 dialectics can be said to represent the initial part of the design process. Their focus is mainly on the relationship between the client and the architect. She states that both should demand quality early in the process, that positive goals as well as open boundaries should be established, and that it is important that the client and architect's visions do not conflict but rather complete each other. She also states that simplicity and complexity should be balanced, that the task should be simplified in order for its complexity to be manageable.

The last three dialects, still handles the relationship between the client and the architect, however, more focus is on the designing and outcome of the building. Both the client and the architect need to be flexible and respect each other's competence and expertise while also keeping their integrity in the process. Teamwork that allows independence is encouraged, as well the having the view that the project should extend beyond its limit, to be greater than expected from the start (Cuff, 1998).

### 4.1.3 Multidisciplinary design approaches

Below follows main features of the approaches by multidisciplinary authors.

**Cecil Balmond**

***Aim***

Balmond's book Informal is not a book about design theory, nor does it strive towards describing an approach for the design process. The book aims more at describing Balmond's way of working when he designs by showing sketches and notes. This study has focused on one of his works, Bordeaux Villa (Balmond, 2007).

***Overview***

Balmond's work is described based on eight days that he remembers from the process, eight days that explains why the design took the form it did (Balmond, 2007). Through interpretations, Balmond's described key events have in this thesis been divided into different main features and activities.

***The approach***

Balmond's work starts by studying the brief, and then he searches for inspiration and main concepts for the building based on the brief. The main concept for this project is that the building should appear to be flying, see Figure 4.9. He also visits the site to find more inspiration, as well as studies previous examples.

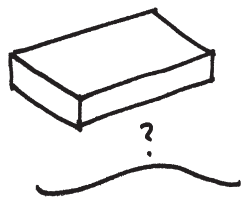



*Figure 4.9 Balmond's sketch of his concept flying (Balmond, 2007)*

Balmond draws analogies to help him find principles for the concept and plays around with different ideas in various scales. His concept guides and inspires him through the process and helps him deal with problems that occur during the process and decisions that need to be made (Balmond, 2007).

**Nigel Cross**

***Aim***

Nigel Cross presents a strategic approach for designing. His approach combines both the procedural and the structural aspects in the design process and is an attempt to create an integrated model for both engineers and architects. The aim is to present a rational approach that is adapted to the characteristics of the design process and its activities that should be performed. It should also be adapted to the cognitive properties of the designer (Cross 1991).

***Overview***

The model describes an overall framework that Cross hopes will describes the essential nature of design problem by showing the relationship between the *Overall Problem, Overall Solution, Sub-problems* and *Sub-Solutions,* seen in Figure 4.10.

Within this framework, a set of design actions are proposed, which are: *Clarifying objective, Establishing functions, Setting requirements, Determining characteristics, Generating alternatives, Evaluating alternatives* and *Improving details.* These activities can either be seen as a sequential process, or simply as activities that supports the design process (Cross, 1991).

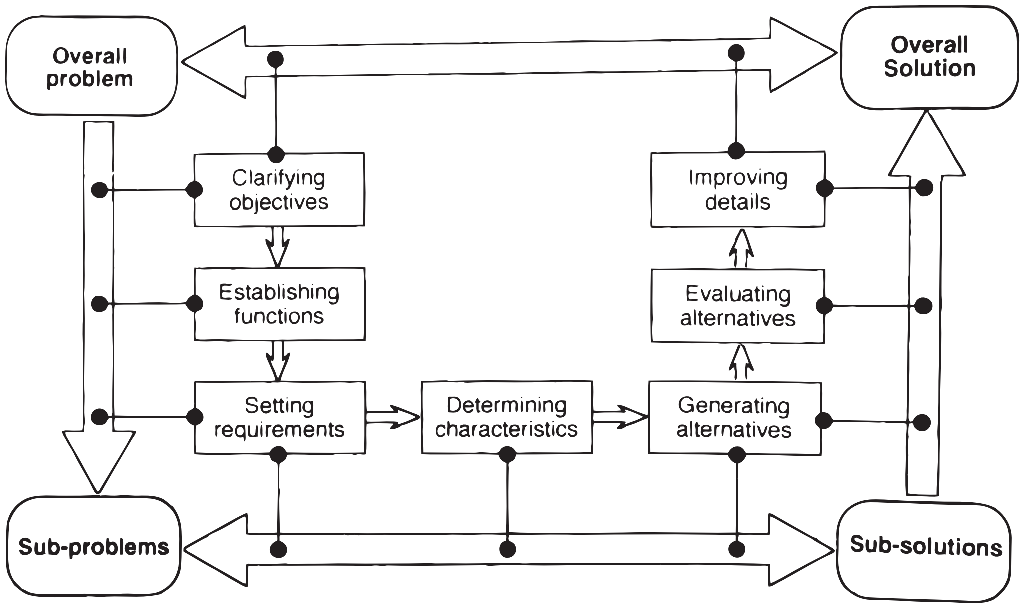



*Figure 4.10 Cross's design process (Cross, 1991)*

***The approach***

Firstly, the model portrays a symmetrical relationship between problem and solution and between sub-problems and sub-solutions. These interactions show that it is not a one-way relationship from problem to solution, but that the problem-definition will depend on the solution concepts and that the generation of solutions will give a deeper understanding of the problem at hand. Similar interactions can also be found between the identifying of sub-problems and the generation of sub-solutions.

The model also shows the designers thinking process, which alternates back-and-forth between the problem/sub-problems and solution/sub-solutions.

The model describes a hierarchical relationship between problem and sub-problem as well as between solution and sub-solutions. This attempts to show that an important and inescapable part of defining the problem is to decompose it into sub-problems, and also the necessity of the sub-solutions to build up the overall solution.

The activities within this framework are: *Clarifying objective, Establishing functions, Setting requirements, Determining characteristics, Generating alternatives, Evaluating alternatives* and *Improving details* (Cross, 1991).

The aim with *Clarifying objectives* is to clarify the design objectives and sub-objectives as well as the relationship between them. This can be done with an Objectives Tree.

*Establishing functions* aims at establishing the required functions and system boundary of the design, and is performed with Function Analysis.

When *Setting requirements* the required performance should be specified with the help of Performance Specification.

*Determining characteristics* aims at setting targets to be achieved to satisfy the client's requirement, which can be performed by Quality Function Deployment.

*Generating alternatives* is performed to find a range of alternative design solutions, as a suggestion with the help of a Morphological Chart.

The alternative design solutions are compared on the basis of performance against weighted objectives in Evaluating alternatives*,* with the help of Weighted Objectives.

Lastly, *Improving details* is performed to increase or maintain the value of the project while trying to lessen the production costs, which can be done by using Value Engineering (Cross, 2000).

### 4.1.4 Organisations approaches

Below follows main features of the approaches described by organisations, both engineering and architectural.

**Architectural organisation RIBA**

***Aim***

RIBA's describes the design process for buildings in their Plan of Work from 2013. They wish the plan will ensure that all the different specialist within an integrated construction team will be able to cooperate and that the framework will serve great purpose for the next design generation. They also wish that the plan will give a straight forward mapping of the design process and that it will also give flexibility for all forms of procurement (RIBA, 2013a).

***Overview***

RIBA's Plan of Work consists of eight key word stages, clearly defined, that organises the progress of designing, constructing, maintaining and operating building projects.

The stages will be compatible with a cross professional work process and is expressed in a draft diagram that illustrates the different stages and the overall framework. They states that the sequence or content of these stages may differ or may overlap, this to suit the procurement method, the project programme and the clients risk profile.

Their different steps are:

*0. Strategic Definition*

*1. Preparation & Brief*

*2. Concept Design*

*3. Developed Design*

*4. Technical Design*

*5. Specialist Design*

*6. Construction*

*7. Use & Aftercare*

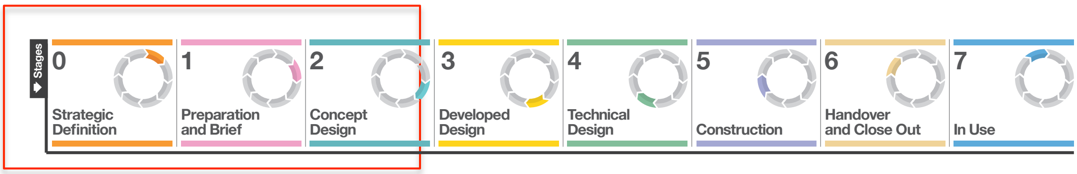



*Figure 4.11 Illustration of RIBA's Plan of Work 2013 (RIBA, 2013a)*

In this study, the first three phases will only be covered.

***The stages***

*0. Strategic Definition*

Stage 0 is performed to strategically appraise and define a project and to make sure that the client´s *Business Case* and the *Strategic Brief* have been studied and understood before the Initial Project Brief is developed. The *Business Case* contains the reasons behind the initiation of a new building project, and is a combination of objective and subjective considerations. The *Strategic Brief* gives definition to strategic considerations to the project, such as considering different sites, refurbish or build new and key outcomes for the project. It should also consist of initial considerations for the *Project Programme* and for assembling a project team.

*1. Preparation & Brief*

The *Preparation and Brief* stage aims to make sure that all preparations necessary are performed so that the next stage, *concept design*, is as productive as possible. Several significant and parallel activities take place, and these can roughly be divided into two categories:

- develop the Initial Project Brief and perform feasibility studies

- assemble the project team and define every participant´s each role and responsibilities and also how to exchange information

The most important task in this stage is to prepare the *Initial Project Brief.* When preparing the brief, on need to keep in mind:

- the project's spatial requirements
- the desired outcomes for the project, which may be found by studying earlier and similar projects
- the site or context, by exploring and gathering information on the site, including building surveys
- the budget

*A Risk Assessment* should also be carried out to determine the risks to each party. A procurement strategy, Project Programme, should be developed.

RIBA points out the importance of properly establishing a project team, to make sure the communication and development of the project will be smooth.

*2. Concept Design*

During the *Concept Design Phase*, the design for the initial concepts of the building is produced. The proposal should be in proportion to the requirements in the *Initial Project Brief*. In parallel with the concept design, the project team will also develop different project strategies which will affect the design in different ways, for example sustainability, fire managements, acoustics, safety etc. The different strategies will influence the project in various degrees.

The *project brief* should be re-examined and updated, and at the end of this stage, a final project brief should be issued.

Parallel to these design tasks, other aspects should also be in progress and respond with the current design: review of the cost information, development of a construction strategy, maintenance and operational strategy and a health and safety strategy. The *project execution plan* should also be updated (RIBA, 2013a).

**Engineering organisation FIB**

***Aim***

In FIB's model code for 2010, they describe the design process and the main intention is to develop and improve design methods and the use of improved structural methods. In order to design for structural safety, serviceability, durability, sustainability etc. certain measures need to be taken in the design stages. The aim for the conceptual design is to design and develop a structural concept (FIB, 2010).

***Overview***

The studied model code describes the conceptual design and the methodology behind it. FIB states that since design problems are large and complex, the basic approach to design will entail decomposition and integration. The problems need to be decomposed and the solutions for the different sub-functions should then be integrated into an overall solution. The complexity of the problem will also make it difficult to establish a methodology for the process. They do suggest a simple map to guide and assist the process, which can be seen in Figure 4.12.

In the conceptual design, a structural concept should be developed that includes a chosen structural system, information about the most important dimensions, construction materials and details (FIB, 2010)

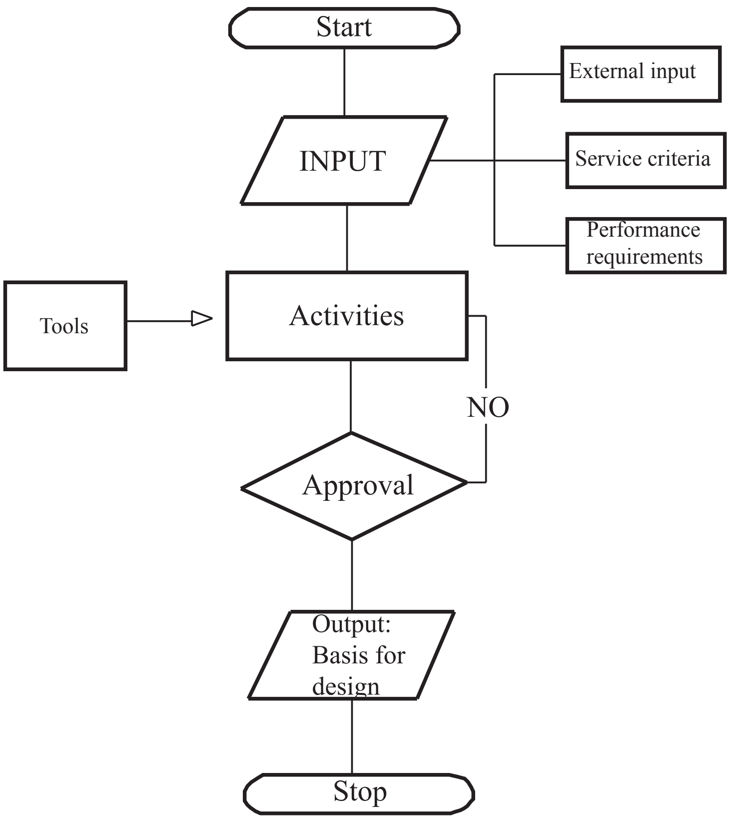



*Figure 4.12 FIB's model of the design process (FIB, 2010)*

***The stages***

First, in the *input-stage,* initial information about the project should be established. The information should be established with regard to: basic external input data, service criteria and performance requirement. Some information will be found through questioning of the client, architects, authorities etc.

The next step includes a series of *activities* that is the main foundation of the conceptual design. These activities are: *formulation, analysis, search, decision, specification* and *modification.*

*Formulation* is the activity of describing the design problem in broader terms. In the *analysis,* the problem is refined, both its description and definition. The important information and essential details should be found, usually by interpretation and prediction. In the *search*, possible solutions that fulfil the requirements are gathered. Many solutions should then be produced that are in line with the specified requirements. These solutions and ideas may be lacking in detail, however, they should still describe functionality, structural bearing capacity, construction and economy. In *decision*, the various solutions are compared and evaluated to find the best solution. *Specification* deals with describing the final solution for further developments. The last activity, *modification*, handles the redesigning of the solution if it is not sufficient (FIB, 2010).

## 4.2 The order of the different phases

By comparing the different authors approaches, described in Chapter 4.1, the main phases or categories appear to be similar even though they may be conceived as different due to used language and terms. However, two different sides seem to be apparent when looking at the structure of the approaches; one side seem to promote a specific order for the execution while the other side rather claims that the phases build up the process without an internal order. The order of the phases, or the lack of order, can be seen as a reflection of the authors view on whether a method should exist or not, as discussed in Chapter 3.1.

*Engineering approaches*

Roozenburg et al. claims in their article *Models in the design process: integrating across the disciplines* (1991) that the engineering approaches have developed into a consensus model. This model describes the design process as a recommended sequence of activities, which will lead to certain intermediate results (Roozenburg et al., 1991).

This seems to correspond to the approaches presented in Chapter 4.1; engineers appear to use a more linear and stepwise approach, seen in both Kroll et al.'s and Pahl et al.'s approach, as well as in Pugh's approach.

Both Kroll et al. and Pahl et al. have structured approaches with a linear flow of work in the process, and both argue for the positive outcome of having a well-structured approach. Kroll et al. believe that a stepwise approach helps the designer to know both his current step in the process, as well as the following step, and he will then be more aware of how to take the design further into the next phase (Kroll et al., 2001). Pahl et al. argues that by working in a stepwise and rational way, they believe the design process will be easier and take less effort and time to select and optimize the solutions (Pahl et al., 2007).

Similarly, Pugh´s model is very systematic, depicting certain phases in a specific sequence. However, even though the steps are portrayed very systematic, he states that they are very iterative and interactive in practice and always overlap each other. The stages are described in a systematic manner for clarity and easier understanding (Pugh, 1990). Correspondingly, both Kroll et al. and Pahl et al. mention that a step-wise structure may not always be performed accordingly in reality. Kroll et al. mention that this type of stepwise structure can function very well for students in their learning of the design process. The same may not be true for practicing engineers, who should use the steps more as guidance (Kroll et al., 2001). Pahl et al. state that intuition and own thinking is very important and that the designer should not blindly follow the steps (Pahl et al., 2007). Even though they all suggest a step-wise approach, where one phase leads to another, they all seem to agree on that the approach should not be followed blindly.

The engineering organisation FIB claims that the process is to complex to be described by a methodology, however, they do actually suggest a simple map to assist the process, which can appear to be linear.

*Architectural approaches*

In contrast to engineering approaches, the architectural approaches do not have a consensus model according to Roozenburg et al., even though they do posses similarities. For example, there seem to be a general rejection of any linear or sequential approaches by the architects (Roozenburg et al., 1991), something that can also bee seen in chapter 4.1.

None of Lundequist, Lawson nor Cuff expresses the design processes as a step-wise and linear approach, instead they describe features of the design process. Lundequist and Lawson both have different categories or groups, representing important parts of the design process. These will together build up the entire design process; however, they are not performed in a specific order. Within these parts, different aspects are considered that reoccurs throughout the entire process (Lundequist, 1998; Lawson, 2006).

Lawson argues that a stepwise structure, often presented as a map, which expresses the design process, as a series of activities following each other in a specific manner is not possible. It is indeed important in a design process for certain activities to happen, however, these activities do not necessarily happen in that order or are identifiable separated activities. Many activities are interactive and depend on each other, which Lawson tries to portray in Figure 4.13 (Lawson, 2006).

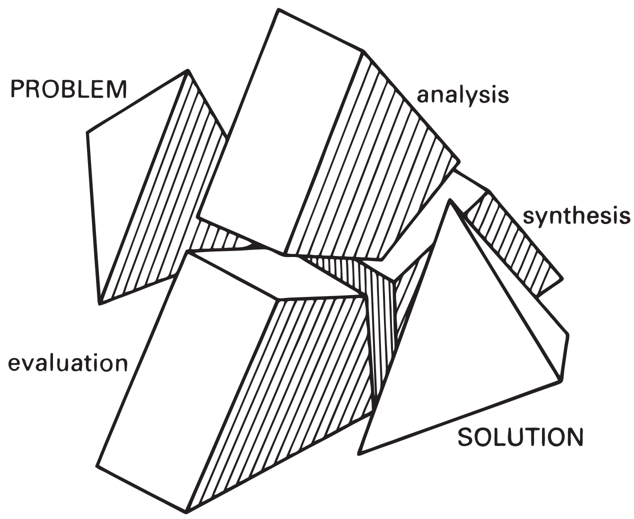



*Figure 4.13 Lawson's attempt towards creating a map of the design process (Lawson, 2006)*

The figure shows how the different phases in the design process are seen as a reflection of the others. It includes analysis, synthesis and evaluation, but has no clear start or finishing point, or direction of flow. However, this map is only a response to the use of stepwise maps and he wishes to give his view on what a map of the design process should look like (Lawson, 2006).

One architectural approach that differs from the others are the organisation RIBA's approach, although their Plan of Work is one of the most widely used models describing the design process. The plan mainly describes what should be carried out in different stages by each professions, and do not describe specific activities to be performed or how the different stages are related (Austin et al., 1999).

*The differences*

From this comparison, a clear difference between the engineering and architectural authors studied in this thesis can be seen. Engineers seem to be more prone to structure their process, while architects appear to strive towards more descriptive views. One approach that does not support any side of the problem is Cross. He suggests a number of activities that are performed during the design process, and that the activities can either be seen as a sequential process, or simply as activities that supports the design process (Cross, 1991).

Why these differences exist can depend on various reasons. Both the professions respective way of working and their tasks will be reflected in their way of structuring and describing the design process.

## 4.3 The phases in the design process

Although engineering and architectural approaches seem to disagree on whether the design process can be structured as a step-wise method or not, when comparing their approaches in an overview level, they seem to have the same features.

*Designers are different, so design processes are different. Still, observing all these individual different processes, it will be clear that all these processes have something in common. This we will call the "structure" of the design process. Knowledge of this structure gives us a standard of the judgement and management of the all the different design processes.*

Boekholt, 1985

Boekholt describes this "structure" by suggesting 3 phases:

Phase 1: Formulation of the design problem

Phase 2: Generation of (intermediate) solutions

Phase 3: Evaluation of (intermediate) solutions

These phases and their interconnection are displayed by Figure 4.14 (Boekholt, 1985).

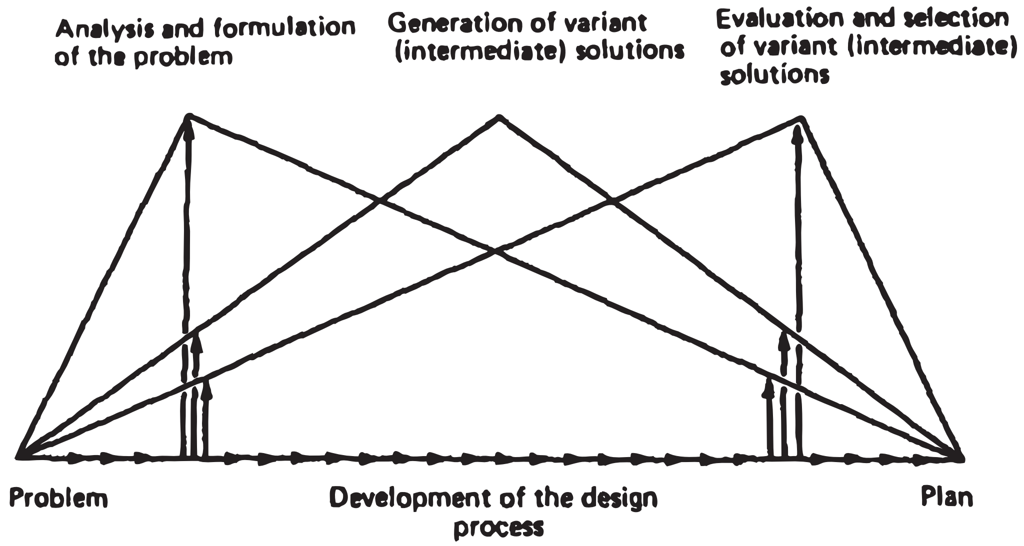



*Figure 4.14 Boekholt's phases and their interconnection (Boekholt, 1985)*

Similarly, Dorst et al. also suggests these main phases in design, only in different words.

*Designers work by framing a problem in a certain way, making moves towards a solution and evaluate these moves...*

Dorst et al., 1995

*Analysis, synthesis and evaluation*

By comparing the different author's approaches in an overview level from Chapter 4.1, the simplified phases described by Boekholt and Dorst et al. can be seen in all approaches. In this study they will be called *analysis, synthesis* and *evaluation,* illustrated by Figure 4.15.

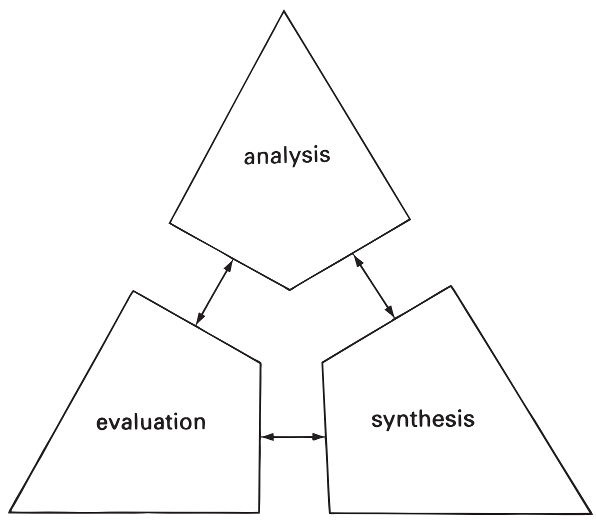



*Figure 4.15* The three phases *(Lawson, 2006)*

Analysis is the information-gathering phase, where the problem is ordered and structured. In the synthesis phase, many different solutions are generated based on the previous step. Evaluation is where the suggestion is critically evaluated against the objectives identified in the analysis phase (Lawson, 2006). This division may simplify the design process very much, however, many authors seem to agree that these main phases do exist. For example, Kroll et al. describes these phases being the general set-up of all engineering design, but that the definition of the terms will differ between authors and practitioners (Kroll et al., 2001).

*The Natural Planning Model*

Kroll et al. also mentions the Natural Planning Model as the basis for all problem solving (Kroll et al., 2001) and perhaps design problems are in fact similar to everyday problems. Maybe all problems will go through the same common, main phases and thereby the core of the different approaches can be said to be similar. The Natural Planning Model is described in David Allen's book *Getting Things Done* (2008) where he argues that all people when accomplishing almost any task goes through the following five steps:

*1. Defining purpose and principles*

The purpose can be defined by asking "why?". By asking different questions of why, the purpose of any project can become clear. A clear a specific purpose can give many benefits: motivation, clarity, decision-making criteria, alignment and creativity. When you know the purpose of a project, criteria and principles for the activity can be established. Criteria represent what drives and directs the activity, and the principles are the standards and values you hold.

*2. Outcome visioning*

This stage defines "what?", and you must possess a clear picture of what success for this specific project would look, sound and feel like. The vision will prove a guide of the final result.

*3. Brainstorming*

When you know what you want to happen and why, the next question to handle is "how?". When an image has formed in you mind of the project and its outcome, the brain starts filling in the gaps by brainstorming on how to get to the end. There are several different ways to brainstorm. Regardless of what brainstorm method is chosen, the goal is to capture and express any idea that comes to mind and to later figure out how it fits in with your project and what you can do with it.

*4. Organizing*

After multiple ideas of how, the brain usually starts organise these. Relationships and structures are noticed and you start to identify the significant components and subcomponents.

*5. Identifying next actions*

The final stage involves taking decisions about what the next action is to get the project moving. If the project has several different parts, the action steps for each part needs to be planed so that they are done in the proper order (Allen, 2008).

By comparing Allen's five phases in the Natural Planning Model, the phases can roughly be divided into the three categories: analysis (Phase 1-2), synthesis (Phase 3) and evaluation (Phase 4-5).

## 4.4 Analysis and synthesis

One important aspect to the design process is whether analysis always precedes the synthesis or if the two phases interact and completes each other.

It seems like engineers more often sees Analysis to be performed before the Synthesis starts. Both Kroll et al. and Pahl et al. have a step-wise approach where analysis is performed and leads the designer to the Synthesis. Both however mentions that the requirements may not be complete in the early stage of a project, it might have to be changed during the process (Pahl et al., 2007). Although they say that the Analysis Phase may be revisited during the Synthesis Phase, they do not see the two phases as simultaneously.

The architects, on the other hand, seem to be more prone to consider the two phases overlapping and contributing to each other continuously. Lawson claims it is not possible to have all the criteria and requirements at the beginning of the process. New requirements will be discovered during the design process. From experiments, he found that most designers have a process with simultaneous analysis and synthesis. Instead of analysing before the synthesis, they explore the problem through their attempts to solving the problem. By combining the two phases, they can also discover more about the problem than by just analysing it. New requirements can arise, and they can realise what solutions are good and what solutions are bad, and why. In these experiments it was found that designers were generating new goals and redefining constraints constantly though the process. It can thereby be said that analysis is part of the whole design process, and that synthesis begins much earlier (Lawson, 2006).

Roozenburg et al. discuss this difference and concludes that in engineering approaches, synthesis should only be performed after the analysis is thoroughly performed. Architects are more prone to combine the analysis and synthesis by generating solution concepts early in the process (Roozenburg et al., 1991). Cross, who presents a multidisciplinary model that is recommended for both engineers and architects, believes that most often, problem and solution needs to be developed side-by-side. By making solution proposals the designer will understand what the problem is more, and thereafter increases his knowledge of what an appropriate solution should be like (Cross, 2000).

The view on whether the Analysis and Synthesis should be performed in a sequence or simultaneously may be based on the two professions difference in the opinion regarding the use of a step-wise method, as discussed in Chapter 3.

## 4.5 Individual or team process

Even though most designs are carried out in groups, the documentation of effective group designing is rather poor. Most often it is the individual process that is described, which Lawson believes partly is a result from the cult and illusion of the individual designer (Lawson, 2006). This can be seen in the respective approaches handled in this thesis, most describing an individual designer, and none of the authors define how their approach should fit in to a bigger collaborative process with the different professions. If teamwork is mentioned, it often refers to activities performed by a group of the same profession.

*Mentioned but not described*

Most authors mention that the design process is performed in teams, often with various professions involved, but seldom described how the cooperation should be carried out. Kroll et al. expresses their view on teamwork within the design process:

*...Engineering design is carried out in an integrated and concurrent manner, and requires effective communication and cooperation among the team members. The cooperation of team members is not just cross-functional but may include team members participating within a single functional area.*

Kroll et al., 2001

Similarly, Lawson states that most often the design process is carried out in teams, however, he believes that at the same time the design process is very personal (Lawson, 2006).

In addition, some authors also describe the benefit with teamwork. For example, Pahl et al. discuss that group dynamics can be very helpful when, for example, brainstorming for possible solutions, inspire others to new ideas or evaluating suggestions. If the group has a well-functioning cooperation they can overcome any lack of information exchange that can be caused by the division of work (Pahl et al., 2007). However, most of these author's approaches seem adapted to the individual designer and does not explain how the teamwork or collaboration is supposed to be carried out.

*Information exchange*

The approaches that do mention teamwork in more detail are the organisations RIBA and FIB. RIBA suggest the following professions and roles are a part of a building design project: client adviser, project lead, design lead, construction lead, architectural design, landscape design, structural design, building services design, cost consultancy, contract administrator, information manager, health and safety consultant. However, their focus concerning collaboration is mainly on information exchange, for every stage they write what exchanges of information should be done as a stage is completed (RIBA, 2013a). Similarly, the engineering organisation FIB describes certain documents and information that should be discussed with the architect or other team participants (FIB, 2010). Even though the organisations do mention teamwork, their main focus lies on information exchange between the professions instead of the collaboration in the creative parts of the design process.

*A common model*

Neither Cross, who aims at describing a common model for the different actors in the process, does mention how the cooperation between them should be carried out, however, he believes that if the two professions have a common model for the design process their cooperation can function better. He aims at achieving this with his model, which can be seen as a hybrid of the engineering and the architectural approaches. He believe that his approach can be used by both professions, and by having a clear and well-organised approach the teamwork can be coordinated so that all contributions are made at the right time in the process (Cross 2000).

A somewhat interconnected process can be seen in the works of Balmond. Even though it is his design process that is documented, the team and their collaborative efforts are described several times throughout the process. Worth mentioning is that the team is very small and familiar, which may have made the collaboration even closer. However, the line between the architect and the engineers work is very diffuse in this project and the personal processes is more or less interconnected with each other and together forms a collective process (Balmond, 2007).

*The social design process*

In general, there seem to be an agreement among the authors that everyone is aware that the design process is a cooperative process, however most authors seem to describe the design process as a solo performance.

*Note that even though designs are often done by teams, in this book we frequently refer to the creator of the product as "the designer".*

Kroll et al., 2001

One reason for why no one describes the social aspect of the design process may be of its complexity. The participants do not share a common set of clearly defined goals or constraints and have different priorities in the design process. In addition, the design process is a dynamic process, in which these goals, constrains and priorities will change (Bucciarelli, 1988).

Although it may be complex, the social process is a very important aspect of the design activity and cannot be ignored. Due to its importance, future methods should consider this social aspect; how the participants interact with each other and different professions and how their social interactions influence both the process and the design (Cross et al., 1995).

## 4.6 Discussion

*Similar phases*

As mentioned in Chapter 4.3, although the different approaches vary between the two professions, they seem to have similar features. In this study these features will be called *Analysis, Synthesis* and *Evaluation.* A few other design theorists such as Boekholt and Dorst et al. agree with this division, however, Pugh consider the view of a design process simply divided into analysis, synthesis and appraisal to be naïve (Pugh 1986). Even though it may be naïve, when comparing the different approaches in Chapter 4.1, they do actually mention these three phases in their approach, only expressed in different ways. Also the Natural Planning Model can be seen to contain these three phases, suggesting that perhaps design problems are similar to everyday problems and that all will go through the same common, main phases.

In short, Analysis is the information-gathering phase, where the problem is ordered and structured. In the Synthesis phase, many different solutions are generated based on the previous step. Evaluation is where the suggestion is critically evaluated against the objectives identified in the analysis phase (Lawson, 2006).

*Differences*

Even though the approaches can be seen to mention the same phases, there seem to be differences between the two professions different approaches. Differences found in this are:

- The structure of the approach: linear or spiral
- Difference in focus: technical or cognitive process
- The relationship between the Analysis and the Synthesis
- Iterative view

*Structure and focus*

From Chapter 4.1 and Chapter 4.2, there seem to be a *difference in the structure* of engineering and architectural approaches. Engineers seem to favour step-wise and linear approaches while architects reject any linear structure.

This was also found by Roozenburg et al. who claims engineering models have a more linear and sequential nature while the architectural models have a more spiral and cyclical nature. Further, the engineering models emphasize the projects expected stages and their sequence, while architecture models are more focused on the cognitive processes that are necessary in the design process (Roozenburg et al., 1991).

From Chapter 4.1, this *difference in focus* can be seen in the various approaches. The engineering approaches, Kroll et al., Pahl et al., and Pugh, all describe the design process by the projects different stages. Pahl et al. approach contains the following stages: *Task Clarification, Conceptual Design, Embodiment Design* and *Detailed Design.* In a similar manner, Pugh's approach is divided into *User group, Brief, Concept, Detail, Construction* and *Sell.*

In contrast, architects seem to reject this type of descriptions and rather describe features of the design process. For example, Lawson describes different *aspects* of designing and designers, which he then summarises into different *groups* representing his view of the design process. In a similar manner, Cuff describes *dialects*, which can be seen as *guidelines* and aims to strive for in the design process.

One way of describing the design process that many of the authors seem to adopt is to suggest what should be done instead of how. This can be seen in both architectural and engineering approaches as well as the organisations. Even the authors, who describe the process in more detail, can in some parts and phases only state the goals and not how they are supposed to be carried out. Perhaps this shows how complex the designing can be.

*Relationship between the Analysis and the Synthesis and iterations*

An aspect that perhaps can explain the differences in structure between the professions is the view on the *relationship between the Analysis and the Synthesis*. The engineering approaches seem to believe that Analysis should be performed before

Synthesis, while the architectural approaches see Analysis and Synthesis as a simultaneous process. Further, the engineering approaches describe that in order to solve a problem, all necessary facts needs to be identified beforehand, while the architectural approaches favour exploring the problem by attempting to solve it.

In agreement to this, Roozenburg et al. believe that in engineering approaches, synthesis should only be performed after the analysis is thoroughly performed, and that architects are more prone to combine the analysis and synthesis by generating solution concepts early in the process (Roozenburg et al., 1991).

The view on the relationship between the Analysis and the Synthesis is connected to the *view of iterations* in the design process. Architects seem more prone to emphasise the iterative process within designing, while engineers seem to give this less focus. Most often, engineering approaches do mention that it is an iterative process and it is sometimes depicted in their illustrations of their approach. However, they may not emphasise it clearly enough or conclude how often or in what way the iterations are made.

*Individual or team process*

One similarity between the approaches is that although most authors acknowledge that designing is a team effort, however, in their actual approaches, they describe an individual process. If cooperation is mentioned, it is rarely explained how it can be performed. This can be seen in RIBA's approach, which discusses the cooperation between different professions but only suggests what documents etc. that should be performed in cooperation, not how the cooperation actually should work. One idea expressed by Cross is that by having a common approach, engineers and architects will be able to cooperate more successfully. However, a description of how this cooperation should be performed seems to be missing.

The phenomenon of describing it as an individual effort might appear as quite strange since most authors seem to agree that the process should be performed in teams. Neither during the education is this collaboration between the two professions adopted or practiced. Since the cooperation between the two professions might be one of the more challenging tasks in the process and work as a foundation to succeed with the design, it is hard to understand why it is not taught in school nor mentioned in the literature.

# 5 The different activities in the design process

As stated in Chapter 4, all of the approaches of the design process contain the same main phases that are called A*nalysis, Synthesis* and *Evaluation* in this thesis*,* each described here in their own chapter. Within these phases, different authors suggest various activities to be performed. In this chapter both what types of activities are suggested and how they are performed will be investigated to find possible differences and similarities between the two professions. The approaches of the two organisations RIBA and FIB will not be described in detail in this chapter since they do not suggest specific activities they rather only describe main features, handled in the previous chapter.

## 5.1 Analysis

The analysis often starts the design process, and its main features is to begin the analysis of the problem, explore the given information, find requirements, limitations and additional information about the problem. The analysis is a very important part since it is the foundation of the design process and decisions made here will affect the following work.

### 5.1.1 Different analysis approaches

#### 5.1.1.1 Different analysis approaches, engineering

Below follows activities in the *Analysis Phase,* described by engineering approaches.

<u>**Kroll et al.**</u>

***Overview and aim***

This thesis's Analysis Phase is referred to as the *Preparation Phase* by Kroll et al. It consists of two main parts, *Need identification* and *Need analysis*, and should result in a requirements list. The aim is to discover what the real need is and to analyse it fully in order to be able to find the most suited solutions. By understanding the need to its full extent, the designer makes sure he or she does not risk disregarding the best possible solutions or creating a too narrow solution space due to having misunderstood the requirements or described them improper (Kroll et al., 2001).

***The activities***

The goal for *Need Identification* is to state what the product should actually do instead of what type of product is desired. Therefore, this step is performed for finding the real need, this by using the black box principle, of which an example is given in Figure 5.1. In the black box principle, the product is considered a black box with input that the product should transform into desired output. Kroll et al. emphasise that it is the problem that should be defined, not the solution.

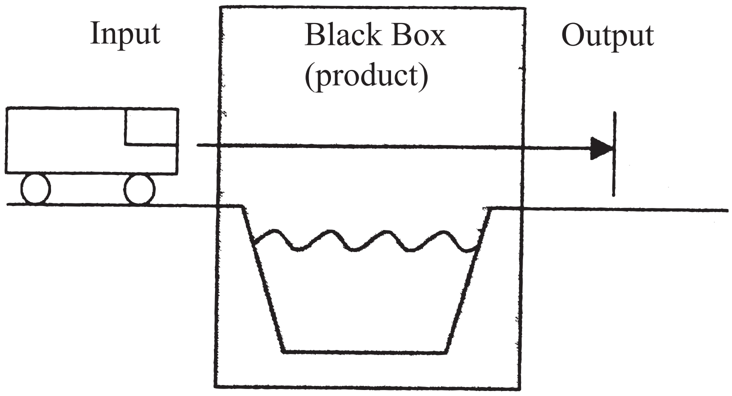



*Figure 5.1 Example of the Black Box principle (Niemeyer, 2003)*

*Need Analysis* is the step where the boundaries are found and defined. Explicit constraints that can be derived directly from the task are listed and together they create a solution space. The solution space should be as large as possible to avoid prejudices and to enable innovation to a great extent. Questions and issues concerning the problem is then listed into five main categorise: performance, value, size, safety and special considerations. These questions should then be answered and investigated, this by carrying out the necessary research.

The *Need Identification* and *Need Analysis* should then be summarised into the *Design Requirements* and a requirement list should be carried out. It is important to avoid writing down the product specifications like performance and properties of the product. Instead, what the product should do and how well should be formulated (Kroll et al., 2001).

**Pahl et al.**

***Overview and aim***

In Pahl et al.'s *task clarification phase* the general and specific requirements and constraints should be identified and formulated and a requirements list should be set up. The main steps can be seen in Figure 5.2. The procedure can be divided into two main steps: *Identifying the Requirements* and *Refining and Extending the Requirements* (Pahl et al., 2007).

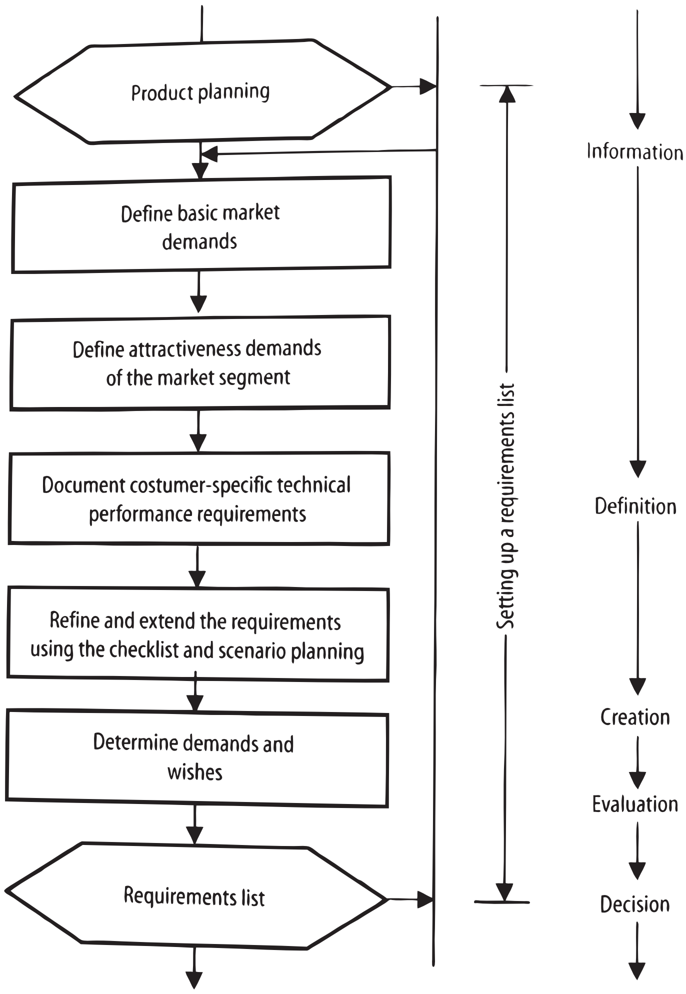



*Figure 5.2 Main steps in Pahl et al.'s analysis phase (Pahl et al., 2007)*

***The activities***

The first step, *Identifying the Requirements,* handles defining and recording requirements. Most of the requirements are often given from the client, stated in a customer contract etc., and can be called explicit requirements. Implicit requirements are not clearly stated, but should be found since they also affect the design greatly.

The implicit requirements can be found in the second step, *Refining and Extending the Requirements*, which consists of finding more requirements and refining them. For this step, two different methods are suggested: *follow a checklist* and *create scenarios.*

When *following a checklist* (see Figure 5.3), the designer goes through a checklist with main categories typical to the special product, for example material or safety, and writes down information, both quantitative and qualitative, for the different categories.

| Main headings | Examples |
|---|---|
| Geometry | Size, height, breadth, length, diameter, space requirement, number, arrangement, connection, extension |
| Kinematics | Type of motion, direction of motion, velocity, acceleration |
| Forces | Direction of force, magnitude of force, frequency, weight, load, deformation, stiffness, elasticity, inertia forces, resonance |
| Energy | Output, efficiency, loss, friction, ventilation, state, pressure, temperature, heating, cooling, supply, storage, capacity, conversion. |
| Material | Flow and transport of materials. Physical and chemical properties of the initial and final product, auxiliary materials, prescribed materials (food regulations etc) |
| Signals | Inputs and outputs, form, display, control equipment. |
| Safety | Direct safety systems, operational and environmental safety. |
| Ergonomics | Man-machine relationship, type of operation, operating height, clarity of layout, sitting comfort, lighting, shape compatibility. |
| Production | Factory limitations, maximum possible dimensions, preferred production methods, means of production, achievable quality and tolerances, wastage. |
| Quality control | Possibilities of testing and measuring, application of special regulations and standards. |
| Assembly | Special regulations, installation, siting, foundations. |
| Transport | Limitations due to lifting gear, clearance, means of transport (height and weight), nature and conditions of despatch. |
| Operation | Quietness, wear, special uses, marketing area, destination (for example, sulphurous atmosphere, tropical conditions). |
| Maintenance | Servicing intervals (if any), inspection, exchange and repair, painting, cleaning. |
| Recycling | Reuse, reprocessing, waste disposal, storage |
| Costs | Maximum permissible manufacturing costs, cost of tooling, investment and depreciation. |
| Schedules | End date of development, project planning and control, delivery date |

*Figure 5.3 Pahl et al.'s checklist (Pahl et al., 2007)*

When *creating scenarios*, the designer imagines different stages in the products life and tries to think what might happen to the product, where it might be used, how it may react, and what properties it then needs to have. The requirements should be refined by asking the following questions:

- *What objectives must the solution satisfy?*
- *What properties must it have?*
- *What properties must it not have?*

In the end of the analysis phase, a *requirements list* should be compiled upon which the design process should be based. The requirements should be placed in a clear order, if possible, by ranking them after importance. The general aspects and the essential problem of the task should be found, and the overall function should be broken down into sub-functions of lower complexity. The requirements may not be complete in the early stage of a project, it might have to be corrected, developed or extended during the later phases (Pahl et al., 2007).

## Stuart Pugh

### *Overview and aim*

Pugh's steps *user group* and *brief* can be said to represent the analysis phase. In the *user group*-step, investigation of the different needs and aspects related to the project at hand should be performed. When the information is gathered it should result in a *brief*.

In order to find and process the necessary information, different analysis techniques can be use. The three suggested by Pugh are: *parametric analysis, needs analysis* and *matrix analysis* (Pugh, 1991).

### *The activities*

*Parametric analysis* is used to identify the project, and to gain insight into the project and the relationship between its different parts. The different relationships should be plotted in a parameter cross-plot. Many plots shall be made (see Figure 5.4), some useful, some not.

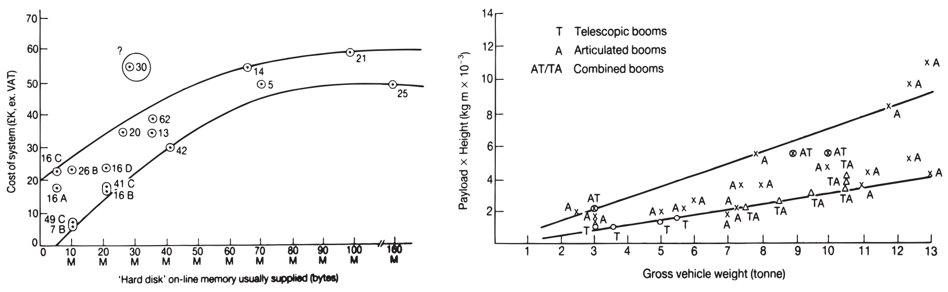



*Figure 5.4 Examples of parametric plots (Pugh, 1991)*

*Need analysis* is used to find the projects true need, where the client's need is given much focus. The needs can be found structured interviews and questionnaires centred on the different elements in the PDS, shown in Figure 5.5.

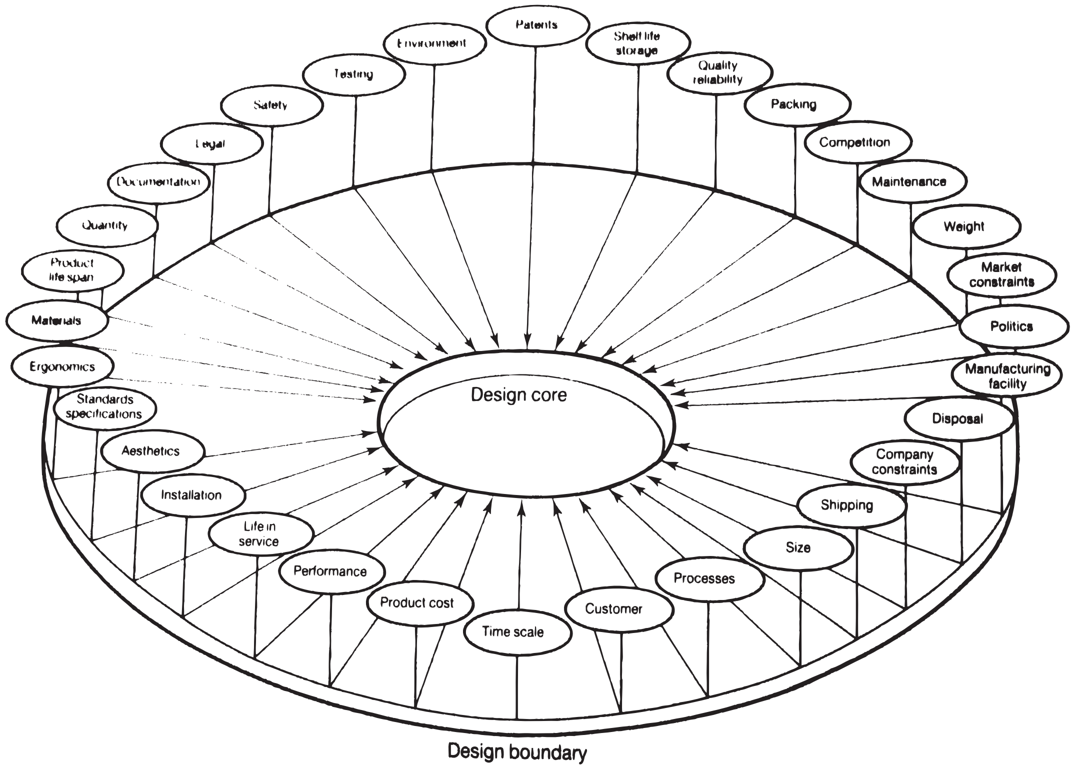



*Figure 5.5 Elements of the PDS (Pugh, 1991)*

*Matrix analysis* (see Figure 5.6) is mainly focused towards product design. In this technique a matrix is drawn where features of comparable products are placed in the vertical axis and the model types are places in the horizontal axis. The matrix will then show what model have which features. This is then summarized and percentage is created for every model that shows how well the model represents all the features (Pugh, 1991).

| No. | Feature and function / Make and model | COOPER VISION | ZEISS (J) SLIT LA. | ZEISS UNIVERSAL | WILD MS – C | WILD MS – B | WILD MS – F | WECK 10108 | WECK (CEILING) | AMSCO, AMSCOPE | KEELER K – 380 FW | ZEISS E.M. CEILING | Graphic representation of percentage | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Coaxial illumination | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | xxxxxxxxxxx | 54 |
| 2 | Moto. vert. course movement | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | xxxxxxxxxxx | 54 |
| 3 | Moto. vert. fine movement | | ✓ | | | | | | ✓ | | | | xxxx | 18 |
| 4 | *X–Y* attachment | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | ✓ | xxxxxxxxxxxxx | 64 |
| 5 | Motorized zoom (microscope) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | xxxxxxxxxxxxxxxxxxxx | 100 |
| 6 | Motorized focus (arm) | | | | | | | ✓ | ✓ | ✓ | | | xxxxx | 27 |
| 7 | Auto. step magnification | | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | xxxxxxxxxxxxxxx | 73 |
| 8 | Hand switch controls | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | xxxxxxxxxxxxxxxx | 82 |
| 9 | Mouth switch | | | | | | | | | | | | | 0 |
| 10 | Foot switch | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | xxxxxxxxxxxxxxxxxxxx | 100 |
| 11 | Counterbalanced by weight | | | | | | | | | ✓ | | | xx | 9 |
| 12 | Counterbalanced by spring | ✓ | | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | xxxxxxxxxxx | 54 |
| 13 | Energized locking | | ✓ | | | | | | | ✓ | | | xxxx | 18 |
| 14 | Friction locking | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | xxxxxxxxxxxxxxxx | 82 |
| 15 | Stepped locking | | | | ✓ | ✓ | ✓ | | | | | | xxxxx | 27 |
| 16 | Rotation free around stand | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | xxxxxxxxxxxxxxxxxxxx | 100 |
| 17 | Vert. course mov. of assy. | | ✓ | | ✓ | ✓ | | | | ✓ | ✓ | ✓ | xxxxxxxxx | 45 |
| 18 | Course mov. in horiz. plane | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | xxxxxxxxxxxxxxxxxxxx | 100 |
| 19 | Vertical mov. of the arm | ✓ | | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | xxxxxxxxxxx | 55 |
| 20 | Tilt of micros. attachm. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | xxxxxxxxxxxxxxxxxxxx | 100 |
| 21 | Rotation of micros. attachm. | ✓ | | ✓ | | | | ✓ | ✓ | ✓ | | ✓ | xxxxxxxxxxx | 55 |
| 22 | Yaw of micros. attachm. | | | ✓ | ✓ | ✓ | ✓ | | | | | | xxxxxxx | 35 |
| 23 | Connection facil. for attachm. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | xxxxxxxxxxxxxxxxxx | 91 |
| 24 | Stand levelling facilities | | | ✓ | | | | | | | | | xx | 9 |
| 25 | Stand braking facilities | ✓ | ✓ | ✓ | ✓ | | | ✓ | | | ✓ | | xxxxxxxxxxx | 55 |
| 26 | Fibre optic illumination | ✓ | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | xxxxxxxxxxxxx | 64 |
| 27 | Down limiting stop | ✓ | ✓ | ✓ | | | | | | ✓ | | ✓ | xxxxxxxxx | 45 |
| 28 | Manual step magnification | | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | xxxxxxxxxxxxxxx | 73 |
| 29 | Slit illumination | | ✓ | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | xxxxxxxxxxxxx | 64 |
| 30 | Manual zoom | | | | | | | | | | | | | 0 |
| 31 | Horiz. mov. on plane of arms | | ✓ | | | | | ✓ | | ✓ | | ✓ | xxxxxxx | 36 |
| 32 | Floor mounted | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | | ✓ | | xxxxxxxxxxxxx | 63 |

*Figure 5.6 Matrix analysis (Pugh, 1991)*

### 5.1.1.2 Different analysis approaches, architecture

Below follows activities in the *Analysis Phase,* described by architectural approaches.

**Bryan Lawson**

***Overview and aim***

Lawson does not express a step-wise approach, but rather describes groups of important activities and skills that are vital for a designer to master in the design process. His group *Formulating* can be said to represent this thesis' Analysis Phase and describes how to understand and formulate a design problem. In addition to the activities and skills mentioned, Lawson also gives a *model for finding design constraints* (Lawson, 2006).

***The activities and skills***

Lawson's group *Formulating* contains the three following points:

*Ways of understanding design problems,* which describes that designers need to be skilled in finding and expressing a design problem, and also to understand and explore them. These activities are called Formulating.

*Identifying,* discusses that a designer should be able to reformulate and structure design problem, even though they can be ill defined at the beginning. Designers should be able to identify elements in the design situation, and from there be able to find the elements characteristics and role, how they will or should work.

In design, a problem can seem different if it is looked at from different points of view. By selectively viewing the design situation in a certain way for a certain purpose, it may be easier to handle the complexity and contradictions in the problem by directing the thoughts and thinking of some issues while suspending others. This method is called *framing*, and is a central skill to direct the process (Lawson, 2006).

*Model for design constraints*

In addition to this, Lawson also creates a model for how to find design constraints. The model is built up by *generators of design problems, domains of design constraints* and *function of design constraints,* which can be seen in Figure 5.7.

There are four generators of constraints in a design problem*: the designer, the clients, the users* and *the legislators*. Each of them impose constrains for the design problem; some impose more rigid constrains than others.

The constraints are often linked to each other by their domain of influence, and can be divided into *internal constraints* and *external constraints*. The internal constraints influence the inner part of the building while the external constrains are constraints that relate the designed object to its context.

To identify and separate different types of functions of design problem, Lawson suggests the use of four categories*: formal, symbolic, radical and practical. Radical constraints* are those that are fundamental to the design problem, *practical constraints* deal with the more technological problems, f*ormal constrains* deal with the visual organisation of the object, and *symbolic constraints* are those that decide what effects the building should have and what it expresses.

The generators, domains and functions are then placed in a three-dimensional block model that shows the structure of a design problem. The model shows how the four different generators can contribute with constraints from the four different functions. These constrains can be either internal or external constrains.

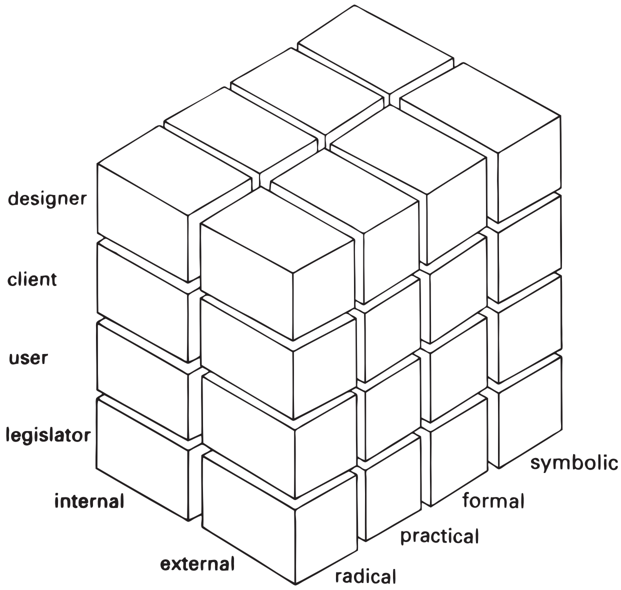



*Figure 5.7 Lawson's complete model of design problems (Lawson, 2006)*

From this model the design process can be conceived, as the designer will direct their attention from one part to another in order to solve the problem (Lawson, 2006).

**Jerker Lundequist**

***Overview and aim***

Lundequist describes four main categories within his three suggested phases. His categories *Information Handling Process* can be compared to this thesis's Analysis Phase (Lundequist, 1998).

***The activities***

The *Information Handling Process* is the most quantitative and comprehensive part of the design process. In this phase, the designer search, process and distribute the information relevant to the project. There are two types of information: *relation – entirety* and *shape – detail*. The *relation – entirety* often occurs in the initial parts, and covers the product as a whole and the relation between its parts. *Shape – detail* is about the products dimensions, colours etc. (Lundequist 1998).

**Dana Cuff**

***Overview and aim***

Cuff neither suggests a step-wise method nor a freer approach, instead she describes seven dialectics that will help the designer creating successful buildings. These dialects do not explain phases or activities in the design process, rather guidelines and tips. Her first four dialects can be said to relate to the Analysis Phase.

***The dialects***

One of the most important parts to a building's possible success is a client´s early and well-informed *demand for quality*. Both the architect and the client should demand quality, and also respect one another´s wishes and interests.

A successful building should be able to balance *simplicity and complexity*. For this to be possible, close contact and easy interaction between the different participants in the process should be made possible. By simplifying for example parts of the procedure or interactions, a buildings complexity can become easily manageable.

For a project to be successful, the architect and the client visions of the design outcome should not necessarily be the same, however it is important that *the visions do not conflict and that they complete each other*, and created a strong bond between two different set of interests. The client shall be active in the design process, but trust the architect when it comes to architectural expertise.

Instead of only creating limitations and boundaries to a project, *open boundaries and positive goals* should be created at the same time. These goals are open and positive, and pursue the architects to perform at his very best (Cuff, 1998).

#### 5.1.1.3 Different analysis approaches, multidisciplinary

Below follows activities in the *Analysis Phase,* described by multidisciplinary approaches.

**Balmond**

***Overview and aim***

Even if Balmond has not divided his work into different phases himself, the analysis part where he collects information, requirements and inspiration, can be found in his design process. Looking at his book and his collection of ideas, thoughts and sketches, the activities he used can be interpreted and analysed. Since he only describes fragments from the process, all activities he actually used will probably not have been brought up. However, the ones he does mention, is those he remembers and probably those that affected the design the most.

***The activities***

After receiving the brief, Balmond starts analysing the problem by creating sketches of the site and exploring the context. From the brief and the needs, Balmond brings up key features and requirements the building needs to have. Based on the requirements, relationships between different rooms and volumes are drawn up.

With the brief in mind, he collects information and inspiration from different buildings, principles and analogies. All these ideas are interpreted into rough sketches, that later helps him develop the concept for the building.

An important part of his Analysis Phase is to visits the site. The visits are intended to inspire and give visions of the different relations on the site, which he explores further in sketches, seen in Figure 5.8 (Balmond, 2007).

*Figure 5.8 Balmond's sketch of the site (Balmond, 2007)*

**Nigel Cross**

***Overview and aim***

The activities in Nigel Cross's model that are connected to analysis are: *Clarifying objective, Establishing functions, Setting requirements* and *Determining characteristics* (Cross, 2000).

***The activities***

Since Cross believes that design problems often can be rather ill defined, one of the first activities is *Clarifying objectives.* This activity handles clarifying the design objectives and sub-objectives as well as the relationship between them. To portray these objective, an *Objectives tree* can be performed, as shown in Figure 5.9. Then design objectives and sub-objectives are clarified and a diagrammatic tree is drawn showing the relationship between the objectives. The branches in the tree represent relationships of how to achieve the objectives.

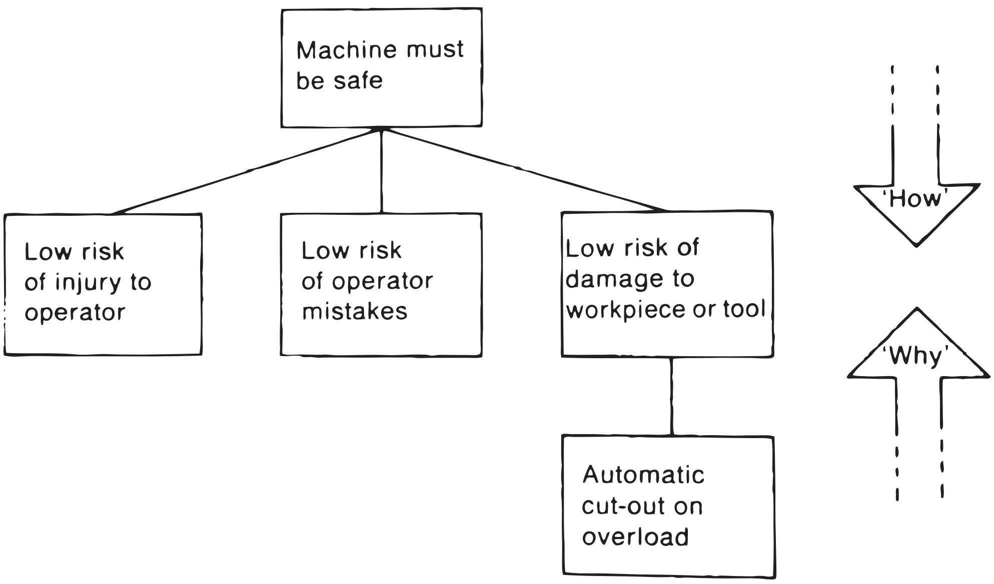



*Figure 5.9 Cross's objectives tree (Cross, 2000)*

*Establishing functions* aims at establishing the required functions and system boundary of the design. By using *Function Analysis* the overall function should be established and then broken down into essential sub-functions so to consider essential functions at the levels at which they are to be addressed.

When *Setting requirements* all requirements regarding the project and its performance should be specified in a *Performance specification,* a list containing all the requirements clearly.

*Determining characteristics* aims at setting targets to be achieved to satisfy the client's requirements. This can be performed by *Quality function deployment,* where a matrix is drawn of attributes against characteristics. Relationship between attributes and characteristics can then be identified in the matrix, and thereby targets can be set up on how to reach the wanted attributes (Cross, 2000).

### 5.1.2 The real need

One of the main features in the Analysis Phase is to find the requirements for the project. Some authors point out the importance of finding the design problems *real need*.

Kroll et al. uses the *Black Box* to find what the client really needs and wishes. He states that it is common for the client to express what they think they need instead of what they actually need, and therefore it is of essence to find these real needs (Kroll et al., 2001). Lawson describes this further by giving an example of one of his old missions as an architect. The initial task, based on the client's wishes, was to design an extension to their villa. Initially, the purpose was rather hard for Lawson to find, since the villa already had all necessary rooms for the family and also since the site was rather cramped and an extension either would have to be placed in the garden or on top of the garage. Lawson thought that regardless to where the extension was place, it was bound to create new problems. However, after more meetings with the clients, Lawson found the real need was the parents wish to not be disturbed by the kids loud music, and the solution thereby became to buy headphones for the kids rather than building a new, quiet room. So by knowing the reel need, the proper solution can be found (Lawson, 2006).

When a client contacts a designer, the client usually states what type of project he wants. However, what the client wants and what the actual design problem is can be two separate things (Kroll et al., 2001). It seems as if both engineers and architects agree that it is the designer's task to find the problem and real need underlying the client's original wish, even though their activities used to find the need may be different.

### 5.1.3 Activities used

In the Analysis, there seem to be a difference in what activities are suggested to be carried out in order to find the real need.

Engineers seem more prone to suggest activities, for example *Need identification, Need analysis, Parameter analysis* and *Matrix analysis* etc. These activities different types of analyses, focused towards creating lists, matrices and diagrams. Often they work within a predefined set of categories for requirements, which can be seen in Pahl et al.'s checklist (Figure 5.3) and Pugh's PDS (Figure 5.5). All activities will eventually lead up to the creation of a *requirements list* or a *brief.*

In contrast, architects rarely suggest activities, they rather discuss the importance to understand the design problem, give general guidelines and suggest different ways of thinking to formulate and structure the problems, such as Lawson's model of design problems, seen in Figure 5.7. Another difference is that architects do not mention the creation of a requirements list or brief in their approaches. Often they state that the brief is given to them by the clients, and that the design problem is then investigated in the analysis.

### 5.1.4 Discussion Analysis

*Differences*

The two professions seem to agree on the goal of the analysis phase, and that it is the designer's task to find the real need of the design problem from the client's original wish. However, some differences can be found between them:

- Focus in the description
- Relationship between the Analysis and the Synthesis
- Suggested activities
- Requirements list
- Sub-functions

*Difference in focus and in view of relationship between Analysis and Synthesis*

Similar to what was discovered in Chapter 4.6, the two different professions *describe* the analysis phase with *different focus*. Engineers seem more prone to describe the analysis phase as the initial step in the projects design process and calls it either Preparation Phase, Task Clarification Phase or User group + Brief. The engineers seem to be of the opinion that the analysis is a preparatory phase in which the problem should be analysed fully before the Synthesis can begin.

In contrast, it appears as architects rather tries to create an understanding of the design problem and describes guidelines and general skills needed to explore and formulate the design process. The architects sees the Analysis phase as a continuous phase in the design process and they seem to believe it will not be possible to have all the criteria and requirements at the beginning of the process. New requirements will be discovered during the design process.

*Suggested activities, requirements list and sub-functions*

The engineers also seem more prone to suggest different *activities* to be performed in the analysis, while architects rarely do. The activities suggested by engineers are often different types of analyses that use tools such as lists, matrices and diagrams. Architects rather aims at giving an understanding of the problem, but gives no specific activities.

All the studied engineering approaches also mention that the Analysis phase should result in a *requirements list or brief*. The architectural approaches do not mention the creation of a requirements list; instead they seem to be of the opinion that the brief is given to them by the client.

Engineers also seem to have a positive attitude towards dividing the requirements into overall functions and *sub-functions*, to make the design problem less complex. In contrast, architects do not share that view of sub-functions and seem to believe there is a risk of loosing the overall focus. However, they seem to believe that the problem have to be looked at from different points of views to handle its complexity, but that this should be done considering the entirety of the project.

## 5.2 Synthesis

The Synthesis Phase is where many different solutions are generated based on the information found in the Analysis Phase.

### 5.2.1 Different synthesis approaches

#### 5.2.1.1 Different synthesis approaches, engineering

Below follows activities in the *Synthesis Phase,* described by engineering approaches.

**Kroll et al.**

***Overview and aim***

After the *Preparation Phase*, Kroll et al. approach continuous with the *Conceptual Design Phase* (see Figure 5.10). This phase consists of three main parts: *Technology Identification, Parameter Analysis* and *Concept Selection*. Their goal with the *Conceptual Design Phase* is to produce as many ideas as possible and to make sure that innovation is emphasised throughout the process. It is therefore important to not have too many restrictions and demands on the ideas that are about to be produced.

In the *Conceptual Design Phase*, Kroll et al. uses many various activities organized into a bigger structure. The big quantity of different activities are used to find as many dissimilar types of solutions as possible, to make sure that the best possible solution is not missed.

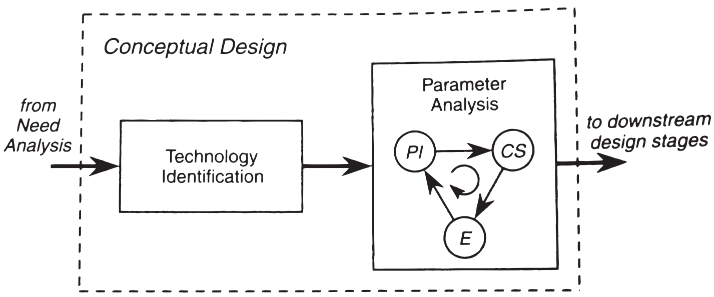



*Figure 5.10 Kroll et al.'s conceptual design stage (Kroll et al., 2001)*

***The activities***

In the step *Technology Identification,* possible technologies that can be used and developed in the process is looked at. The goal is to prepare for the *Parameter Analyse* and to select a core technology.

*Parameter Analysis* contains the three parts: *parameter identification (PI)-creative synthesis (CS)-evaluation (E).* These three are connected in an iterative loop, handling one or a few parameters in one loop.

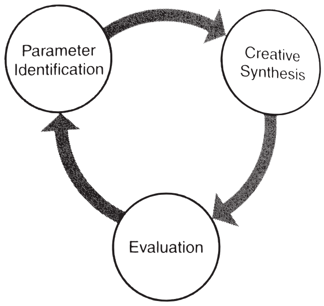



*Figure 5.11 Schematic of the parameter analysis methodology (Kroll et al., 2001)*

*Parameter Identification*

In the *Parameter Identification (PI),* all the main parameters should be found. To find what parameters to start with, two activities are suggested: *stripping the task of less important considerations* and *make-or-break issues*. *Stripping the task of less important considerations* helps deciding what problem should be solved when since not all issues can be solved right away. If the task is complex it will be more manageable to focus on one or a few problems at a time. It can also help focusing on *make-or-break issues*, issues and aspects that are those jeopardizing the whole design and should be identified and solved first.

If the underlying problem is difficult to find, or to complex to visualize, Kroll et al. suggest that it can be useful to develop *simple models to understand governing relationships*. In this activity models are build to capture some essential relationships that is to complex to understand right away.

When the parameter is found, it can be helpful to use a concept from another artefact or field with the same kind of parameter or aim, called *analogical thinking*.

If the designer gets stuck whit the design, several different activities are recommended to get back on track: *Rephrasing the task statement, Explaining the cause of a problem in a different way, Stepping back* and *Parameter substitution*. All of these activities aim to help the designer to take the product further.

*Creative synthesis*

The *Creative synthesis (CS*), is the generation of physical configurations based on a concept recognized within the previous step, *Parameter Identification (PI).* If *PI* can be indicated as active in the concept space, the *CS* is a realization of *PI* and set in the configuration space. In *CS*, new key parameters can also be found and will then be adopted in the *Parameter Analysis* loop.

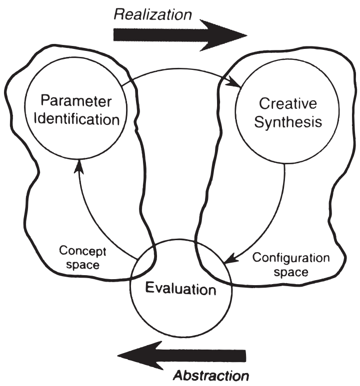



*Figure 5.12 Correspondence between the parameter analysis methodology and the concept and configuration space (Kroll et al., 2001)*

To generate suggestions in *CS*, two different activities are used: *identifying constituent elements* and *integrating constituent elements*. The first activity the designer identifies several components or parts from the entirety and in the second activity, these different parts will be explored and possible solutions found. These different partial solutions will be integrated to form a complete solution.

The last step in the loop is the *evaluation (E)* of the concepts that are first found in *PI* and then developed in *CS*. After the *evaluation (E)*, covered in Chapter 5.3.1, the loop restarts and new parameters to the design are discovered and developed.

**Pahl et al.**

***Overview and aim***

The first part of Pahl et al.'s *Conceptual Design Phase* (see Figure 5.13), where a solution principle is found and elaborated, is comparable to this thesis's Synthesis Phase. The solution principle is found by: *identifying the essential problem* and *establishing function structures* (overall function and sub-functions), *generating suggestions for solutions* to fulfil the sub-functions and *combining these into a working solution* (Pahl et al., 2007).

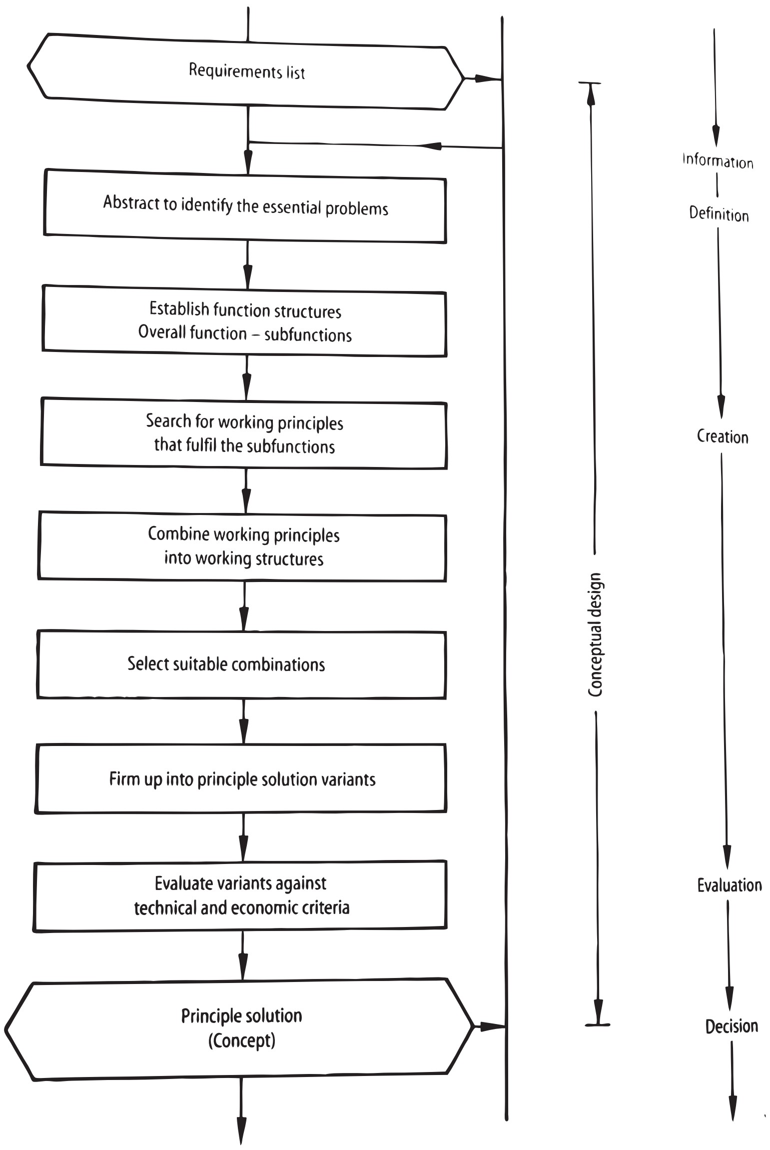



*Figure 5.13 Steps in Pahl et al.'s conceptual design (Pahl et al., 2007)*

***The activities***

The first part in the Synthesis Phase is *Definition*, where the essential problem is identified and the overall function is broken down into sub-functions of lower complexity. The aim is to find sub-functions that will give rise to sub-solutions that when combined create a function structure that will represent the overall function.

After the definition phase, the *Creation* begins. First, the *generation of solutions* starts by searching for solutions for every sub-function to create a solution field so that each sub-function has several solution variants. The activities that can be used to generate solutions to the sub-functions are *literature searches, analysing natural systems, analysing existing technical systems, analogies* and *intuition-based methods*.

These different solutions are then placed in a matrix, a so-called *morphological box*. A morphological box is a matrix where the sub-functions are the row headings and the possible solutions to the sub-functions are entered in the same row.

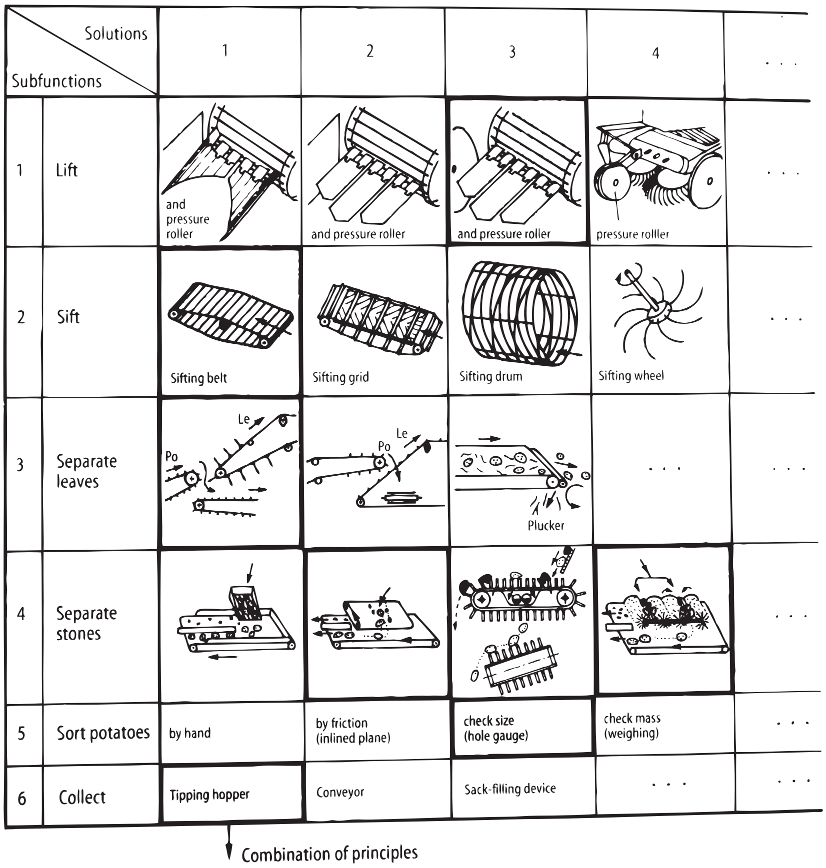



*Figure 5.14 Example of the morphological box (Pahl et al., 2007)*

These different solutions are then *combined* so that a working solution for one sub-function is combined with a working solution for another sub-function to create an overall working solution. This combination is done by systematic combination, which is based on the morphological matrix done in the previous step. Then compatible solutions for every sub-function are combined into an overall solution by concentrating on promising solutions and determine why they should be chosen. The difficult part in this activity is to know which sub-functions are compatible.

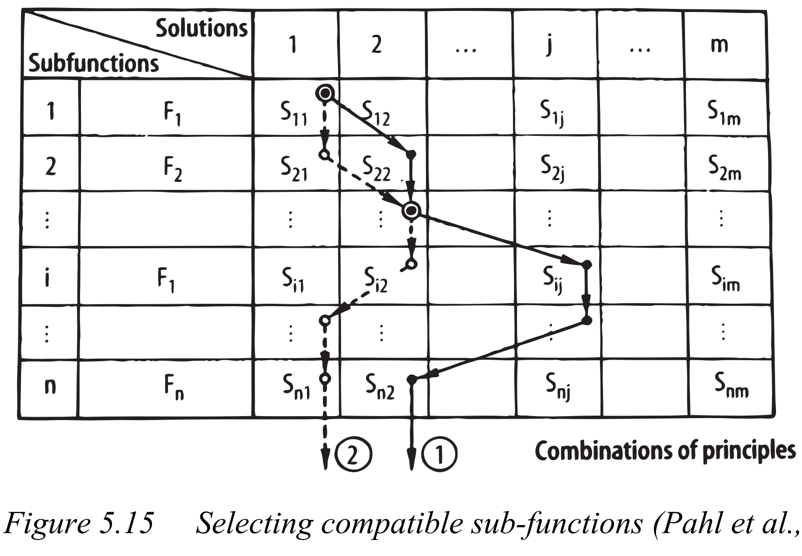



*Figure 5.15 Selecting compatible sub-functions (Pahl et al., 2007)*

Pahl et al. states that before the chosen solutions can be evaluated, they should be firmed up; all the important characteristics should be known and all the important properties should be given qualitative and quantitative definition. The firming up can be performed through rough calculations, rough sketches or scale-drawings, preliminary experiments or model tests, construction of models and analogue modelling and system simulation (Pahl et al., 2007)

**Stuart Pugh**

***Overview and aim***

Pugh's step *Concept* is mainly focused on generating solutions that meets the requirements and needs, and can therefor be said to represent this synthesis phase. The conceptual phase can be divided into two cyclical, major components: *generation of solutions to meet the need* and *evaluation and selection of the solution that meets the PDS the most. (Pugh 1991)*

The techniques to describe how to generate solutions will be covered in this chapter, while the evaluating techniques will be handled in chapter 5.3.1.3.

***The activities***

In this step, as many solutions as possible should be generated. Even though they can be very undetailed, they still need to work within the physical laws. Some calculations should also be carried out in order to determine the viability of every solution. In addition, the generated concept should also consider the context of the project at hand.

The techniques most common for generating ideas are: *analogies, brainstorming, attribute listing, checklists, inversion* and *combination.* Due to *analogies* and *brainstorming* being more well known, they will not be described further here. In *attribute listing*, different attributes of an artefact are used to find new ideas. Attributes could be: *Shape – round, square, etc*. or *weight – heavy, light, etc. Inversion* takes advantage of existing ideas and manipulates them, for example by thinking "upside down", "inside out", "reversed" etc. *Combination* also uses existing solutions, where their parts are combined in new ways (Pugh, 1991).

#### 5.2.1.2 Different synthesis approaches, architecture

Below follows activities in the *Synthesis Phase,* described by architectural approaches.

**Bryan Lawson**

***Overview and aim***

Bryan Lawson's group *Moving* can be said to represent the Synthesis Phase. It describes skills that involve making suggestions of design solutions, i.e. making moves to solve the problem (Lawson, 2006).

***The activities and skills***

The group *Moving* contains the three following points:

*Creating solution ideas,* which is very important to the design process, and there are several activities that can be used to make these design moves.

*Primary generators* are early, often relatively simple, ideas of the solution that designers make before really understanding the problem. These primary generators, also refer to as concepts, can help the designer explore the problem and find solutions. The choice of the primary generator is often based on the designers guiding principles and it should involve the issues that are central and critical to the design problem. The generator is often used to restrict the possible solutions and to focus the attention on a selected amount of constraints in order to quickly find ideas for solutions of the problem. These primary generators can sometimes have influence all throughout the design process, both in macro and micro levels.

*Interpretive and developmental moves,* describes different moves. Some moves can be entirely new, although very unusual, and some moves already exist but is interpreted and transformed to fit the design problem at hand. These interpretive moves involve transformation of an already existing idea into a different solution but that still contains some of the original idea's characteristics. In design, moves are often developed further, given more detail etc. to move closer and closer to the desired result for the particular situation, and these moves are called developmental (Lawson, 2006).

**Jerker Lundequist**

***Overview and aim***

Parts of two of Lundequist's sub-processes (as seen in Figure 4.8) can be said to contain activities related to the Synthesis Phase. The first sub-process, *the artistic*, contains creating and designing suggestions. The second sub-process, *the problem solving and handling*, handles problems that arise in the process.

***The activities***

The *artistic processes* connected to the syntheses contain the designer creating and designing constrained but meaningful entirety. These different suggestions will be displayed, discussed and then evaluated by the project team.

The *problem solving and handling processes* deals with arising problems by experiments performed in a created model-world for the project. In this model-world, the product and its future surroundings are portrayed (Lundequist, 1998).

**Dana Cuff**

***Overview and aim***

The last three of Cuffs dialectics can be said to contain guidelines within the Synthesis Phase.

***The dialects***

The following dialects are related to the Synthesis:

One important aspect to a successful building is the *flexibility* that both the architect and the client can bring to the process. By respecting each other's competence and expertise, the two parties can be more open-minded and resolve upcoming problems rather harmoniously and embrace the evolution of the design process. However, it is also important to recognise i*ntegrity* within the flexibility, to stand up and voice the different opinions that may arise in the process.

*Teamwork* and collaboration throughout the process is emphasized, however, the team does not need to be bonded together in every step, participate equally or collaboratively. Key individuals can instead play key roles, and together they move the project along by coordinating the different contributions well.

With regard to the buildings outcome, Cuff highlights the basic rule "give more, get more". In order to create an excellent building, both the architect and the client usually have to *exceed the limits* and go beyond what was planned, to hopefully end up with a building that captures what they could not articulate in the beginning of the process. This requires the architect having freedom to invent design solutions that the clients most often could not have imagined themselves. A consequence is often that the budget will be exceeded; however, Dana Cuff sees this as necessary means for the building to go beyond what was planned into excellence. (Cuff, 1998)

#### 5.2.1.3 Different synthesis approaches, multidisciplinary

Below follows activities in the *Synthesis Phase,* described by multidisciplinary approaches.

**Cecil Balmond**

***Overview and aim***

For his Bordeaux Villa, the main feature the Synthesis is that he starts from a concept or vision and creates several possible suggestions based on that vision. The suggestions mainly consist of different principles or analogies that Balmond explores. He does not seem to have a specific predefined route, and it appears as if he solves the problems as they arise.

***The activities***

Balmond uses several different activities to find concepts, which is mentioned briefly. One of the main activities described is finding key words to accompany the concept. For this project, the concept was to make the building fly and two of the key words were flying carpet and hover. From these key words brainstorming was performed to find working principles for the structural system of the building, and the different suggestion are explored in sketches.

By sketching different suggestions, Balmond discovers the underlying problem as the balance between gravity and equilibrium. From this realization, with the help of analogies, Balmond explores the underlying principle for the problem and plays with balance to find what type of feeling he wish to accomplish with his volumes.

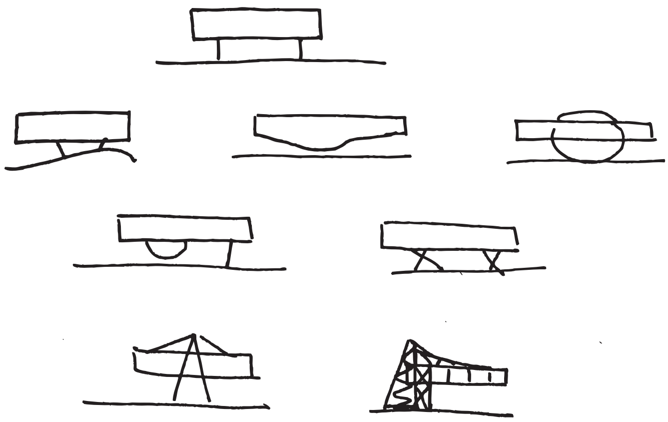


*Figure 5.16 Balmond's sketches playing with gravity and equilibrium (Balmond, 2007)*

After finding volumes he prefers, he goes more and more in to detail with support from his previous concept and key-words.

**Nigel Cross**

***Overview and aim***

Cross's action *Generating alternatives* is performed to find a range of alternative design solutions and can be seen as the Synthesis Phase. To generate different alternatives a *Morphological chart* can be performed.

***The activities***

The generation of concepts is a central part to the design process with the main purpose to generate something new. Although the final design should be considered new, many design ideas originates from existing solutions. Therefore re-ordering or re-combination of existing alternatives is an important part of generating solutions. The *morphological chart*, similar to the morphological box by Pahl et al., can be used to explore this phenomenon, to encourage the designer to find possible sub-solutions to be combined into an overall working solution. (Cross, 2000)

### 5.2.2 The word concept

Both architects and engineers consistently use the word concept in the descriptions of the design process. However, since the word can be rather diffuse, there is a great possibility that the word is both interpreted and used differently by the two professions.

When describing the concept, also often referred to as the primary generator, Lawson brings up the two following examples for a primary generator: create a mews-like street and leave as much open space as possible (Lawson, 2006). In Balmond's Bordeaux Villa, the concept is that the building should appear to be flying (Balmond, 2007). Pahl et al. and Niemeyer both mentions systematic search as a way to generate a wide range of possible design concepts, and examples of these concepts are then displayed as drawings of different structural systems (Pahl et al., 2007; Niemeyer, 2003).

The engineering organisation FIB gives examples of how to decide a concept, in this case for bridges, by showing various examples of bridge types such as a girder bridge or a cable stayed bridge. The concepts seem mainly connected to span length and supports (FIB, 2000).

From this, it appears as architects and engineers have a different view and definition of the word concept. The difference in choice of concept may partly depend on where the designer tends to lay his focus. A concept is often used to restrict the possible solutions and to help focus the attention on a selected amount of constraints in order to quickly find ideas for solutions of the problem. The concept should hopefully involve the issues that are central and critical to the design problem. However, what is seen as most central and critical, and thereby the concept, will vary from designer to designer, and also between different design fields and problems (Lawson, 2006).

Even though both professions may define different types of concepts, they seem to be convinced that concepts are vital to designing. Kroll et al. mentions that often the best ideas are usually quite simple conceptually, and if so, creativity is more successful or productive solving simple problems rather than complex problems (Kroll et al., 2001).

Lawson continues discusses the possibility of better cooperation between the two professions if they were to share the same focus and concepts. For example, he claims that buildings with the concept "structural honesty" have been shown to lead to a design process where engineers and architects worked closely together to develop a proper structure (Lawson, 2006).

### 5.2.3 Creativity and generating suggestions

In all the previously described approaches, generating ideas is a major part of the synthesis, and creativity is seen as the foundation of the idea generation. Creativity can be described in several different ways and for various reasons. One description is that creativity is the ability to produce new and useful ideas as a reaction to a problem or a need, and that creativity entails the breakout from fixed thinking structures (Niemeyer, 2003).

*A model for creative thinking*

In his book, Lawson gives what he believes is a common description of the creative thinking process as a five-stage model. He identifies the phases: first insight, preparation, incubation, illumination and verification.

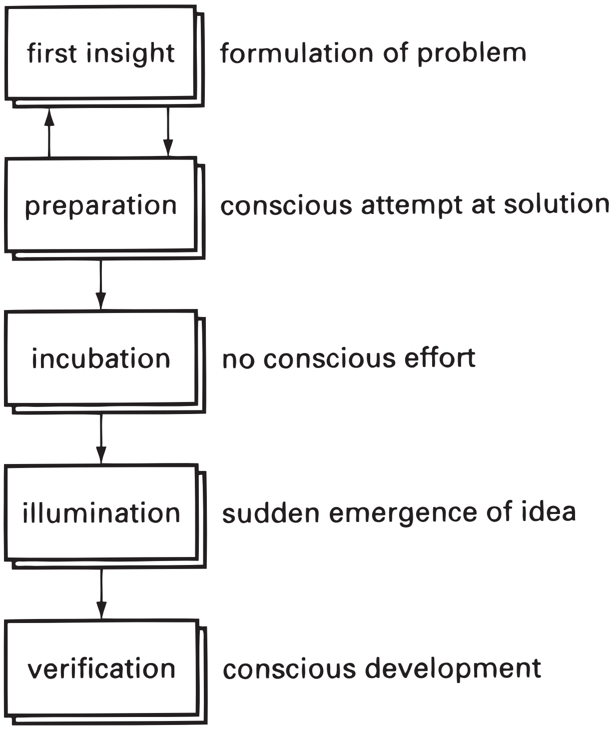



*Figure 5.17 Lawson's five-stage model for creativity (Lawson, 2006)*

The first step, fist insight, involves recognising a problem and setting out to solve it. The second step, preparation involves exploring possible solutions. The first two stages will affect and interact with each other. After the preparation, a phase of incubation follows. This phase is more relaxed where the designer is able to relax its mind and think about the data collected in the previous steps. After the incubation, a phase of illumination often occurs, a sudden emerge of a suitable idea. In the last phase, verification, the idea is tested, elaborated and developed (Lawson, 2006). Niemeyer, an engineering student, also describes the creative process with similar phases: preparations, incubation, enlightenment and verification, in his master thesis a comparative study of engineers' and architects' approaches in the design process (Niemeyer, 2003).

*Contributing factors*

Many authors, both architects and engineers, suggest similar activities for how to be creative and generate suggestions. They also mention different factors that can contribute to increasing the potential for success when using creative thinking. Most activities suggest the designer to have an open mind and to be free from judgement. This will make all team members to feel safe in the team and thereby be able to express ideas, even though they may appear silly at first (Pahl et al, 2007; Kroll et al., 2001; Hörngren, 2008). Designers should neither have to high demands or expectations on creativity, since there are no guaranties for if and when creativity will arise and how qualitative the idea may be. However, this is a necessary part of the creative process nonetheless and should not be seen as a waste of time (Kroll et al., 2001; Pahl et al., 2007).

By being a well-functioning team in the creative process, the participants can stimulate and inspire each other. This can increase the possibilities for lateral thinking. Lateral thinking can according to De Bono be compared to digging several holes; instead of digging deeper into one hole, the solution field is broadened and thereby the chance of finding the best possible solution increases (Hörngren, 2008).

*Different types of creativity?*

Creativity is most often mentioned in the different approaches as the foundation for generating suggestions, and is therefore an important part of the design process. It seems as if both professions consider creativity to have the same basic steps and they seem to suggest similar activities and contributing factors to creativity.

Still, the type of creativity used for the two professions may differ, which is discussed further by Lawson. He says all designers need to be creative, however, some designers, such as architects, need to have a highly developed visual sense while others, such as engineers, need more numerical skills in order to achieve their design goals (Lawson, 2006). Suggesting that even though they share a common definition of creativity, it may be used different for the two professions, perhaps due to their background and expertise.

### 5.2.4 The use of previous examples

In his book *How Designers Think*, Lawson writes about Margaret Boden who in 1990 divided creativity into H-creativity and P-creativity. The results from H-creativity are new ideas in the history of the world while P-creativity contains ideas that are fundamentally novel to the designer but not new to the world. H-creativity is rather rare; however, P-creativity is very important to designers. This type of creativity may not necessarily be breaking news, but by taking inspiration from old principles and examples designers can create new innovations (Lawson, 2006). In this thesis, many of the described approaches discuss the use of previous examples and experiences.

*The different views*

When using previous examples, engineering approaches seem to be more interested in the structural system than other qualities such as expression or design features. For example, FIB uses previous examples when showing different concepts for bridges (as mentioned in Chapter 5.2.2) and then categorises these examples by what structural type the bridge is (FIB, 2000).

Similarly, Pahl et al. also seem to focus more on structural properties in their usage of previous examples. They consider the analysis of previous examples to be fairly similar to a form of structural analysis in which the related physical, logical and embodiment design features are found. The finished products are examined and dissected into sub-functions to find their good or bad characteristics, and the gained knowledge is used to create new or improved variants of the studied solution. The analyses can be of similar products, older products or parts of other products. They believe this method can be very effective to find solutions concepts as a starting point; however, designers need to be careful not to stick with these old solutions instead of pursuing new ideas inspired from the old solutions (Pahl et al., 2007).

Also Kroll et al. mention that using previous examples is important but that the designer should be aware that if using it too much or too soon in the process, the creativity and the development of the design might be inhibited (Kroll et al., 2001).

In agreement with engineering approaches, the architectural approaches believe that the use of previous examples is a very important source of inspiration. In Lawson's model, in his group *Moving*, he describes the usage of old examples and ideas as interpretive moves, which he sees as an important activity to generate solutions that designers need to master (Lawson, 2006). Similarly, Schön emphasises that the use of previous examples is central to the problem handling in design. Decisions and ideas are partly based on a practiced skill to see the similarities in the problem at hand to previous problems whose solution is known. Schön stresses that this is very different from copying, instead the designer has a repertoire at his disposal from which he can find relevant similarities and differences between the new and the old problems and take inspiration from these. Schön describes the activity of using previous examples as the designer seeing the new problem A as the know problem B, and by comparison the gap between them can be found from which new ideas can arise (Schön, 2001).

*The differences*

There seem to be an agreement among the authors that experience and old examples are an important part in designing, and they all emphasize that simply copying old solutions should never be done. However, in spite of this, there seem to be a difference in the actual execution and focus of the activity if comparing an example of usage of previous examples by Pahl et al. with Balmond.

Pahl et al. gives Figure 5.18 as an example of how an analysis of existing technical system can be performed. The product is divided in sub-functions, whose different features are described. The designer is then offered the possibility to take inspiration from these sub-functions and their features (Pahl et al., 2007).

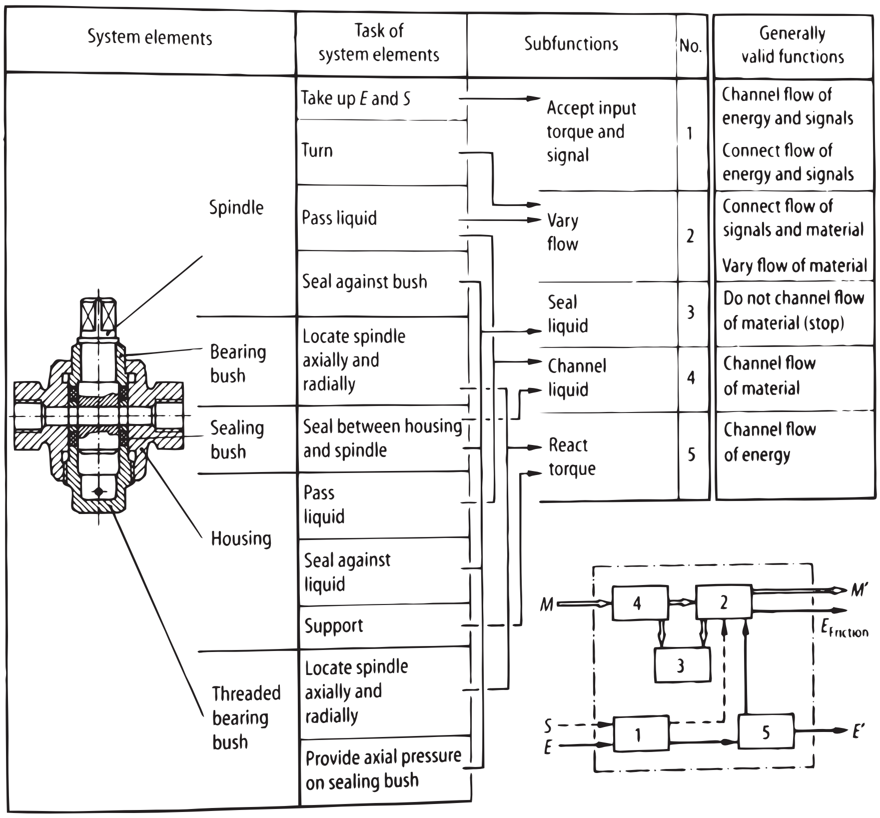



*Figure 5.18 Pahl et al.'s example of analysis of technical systems (Pahl et al., 2007)*

This example can be compared to Balmond Bordeaux Villa. From his concept that the villa should appear to be flying, he finds inspiration from old buildings he believes have similar characteristics to his concept (Balmond, 2007).

*Figure 5.19 Balmond's sketches of old buildings he believes have the characteristics of flying (Balmond, 2007)*

Engineers seem more prone to focusing on the structural features from previous examples while architects more seem to seek general inspiration from them.

## 5.2.5 The use of analogies

Using analogies is an activity suggested by several authors, both engineering and architectural, when generating ideas and possible solutions.

Pahl et al suggest analogies to be used to generate solutions. Analogies may be both from the technical and the non-technical sphere and can help the search for solutions and also for understanding the behaviour of a system. They give an example of how analogies can be found by showing how sandwich constructions can be derived from honeycomb structures (Pahl et al., 2007)

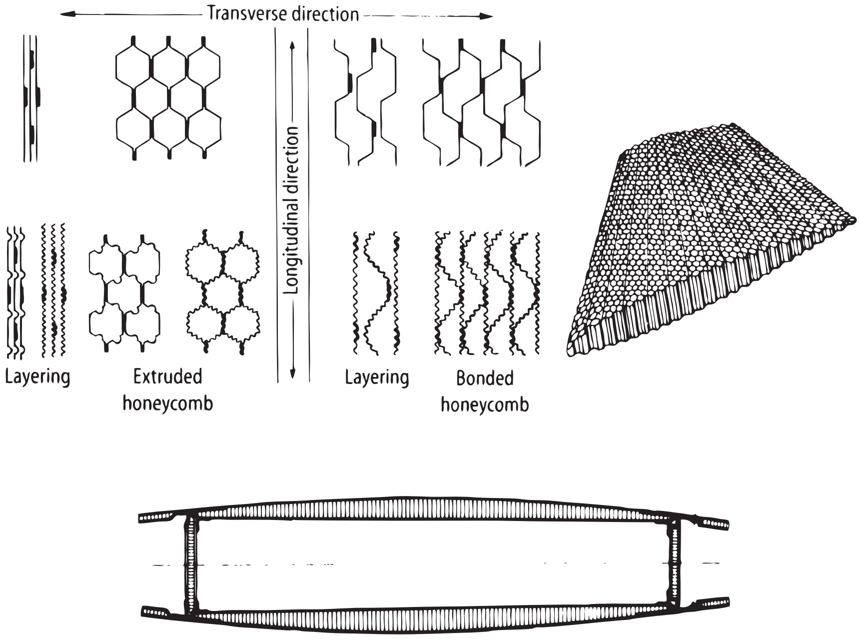



*Figure 5.20 Analogies of a sandwich construction (Pahl et al., 2007)*

(Pahl et al., 2007). Also Kroll suggest *analogical thinking* in the parameter identification phase. He gives the example of airbags, which have been derived from how the cushioning of the landing impact on Mars was performed. He also mentions that analogies can be more conceptual (Kroll et al., 2001).

The more conceptual side to analogies can be seen in the works of Balmond. He uses analogies throughout the process, in different scales. Both for construction principles as for certain feelings that he wishes to accomplish with his design.

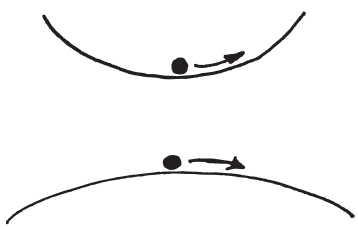


*Figure 5.21 Balmond's conceptual sketches his desired feeling for balance (Balmond, 2007)*

Analogies can help describe complex things and increase the understanding of what is really explained or strived for. They can even be used in the everyday life to explain situations or feelings that may be hard to put into words. Design ideas can sometimes also be hard to convey, and perhaps even harder to be understood between different professions. By using analogies, there is a possibility that the idea can be understood more rapid by outsiders; however, at the same time there is a risk of increasing the gap between the professions if the analogy is too far-fetched. For example, Balmond's flying carpet can either make outsiders easily understand what Balmond strive for, but it can also be interpreted in various ways and also be confusing if the analogy is taken too seriously.

### 5.2.6 Sub-solutions

All professions probably agree that if a design problem is very complex, it is necessary to divide it into smaller focus areas to make it more manageable. However, the opinions seem to differ on how and how much the problem can be divided.

Roozenburg et al. claims that engineering approaches, following the engineering consensus model, split design problems into sub-problems for which sub-solutions should be found for each sub-problem and than integrated to form an overall solution (Roozenburg et al., 1991) This can be seen in Pahl et al.'s approach, where *systematic search* is used to split the design problems into sub-problems and then solved piece by piece by finding different concepts for sub-functions (Pahl et al., 2007). Also FIB encourages sub-problems and sub-solutions. They states that since design problems are large and complex the design problems need to be decomposed and the solutions for the different sub-functions should then be integrated into an overall solution (FIB, 2010).

The engineering view on sub-solutions has received criticism from architects. Roozenberg et al. say that by dividing a problem into sub-problems it can lead to an uncontrollable explosion of possible sub-solutions. Further, when appearance is important, the total form should be determined either before or in relation to the different parts and not be a result of the combined parts (Roozenburg et al., 1991). Similarly, Lawson also discusses possible flaws with the use of sub-solutions. He believes it is hard to isolate them on their own since the essence of a design problem is the connection between its sub-problems. By changing one factor, the whole will change. However, Lawson do suggest a version of the sub-solutions called framing, used in the analysis of the design problem, in which the design problem is looked at from different views in order to make it less complex but still keeps the entirety of the project in mind (Lawson, 2006).

Even though Cross, a co-author with Roozenberg, recognises these risks with using sub-problems, he still encourage the use of it in his own model of the design process. However, he incorporates it with a different thinking where the designer needs to have the entirety of the project in mind (Cross, 2000). Since Cross claims his model is to be used by both engineers and architects, maybe sub-problems and sub-solutions are inevitable in the design process. The disagreement may lie in how roughly the division is performed, their relationship to each other and how they form an entirety.

### 5.2.7 Discussion Synthesis

Similarly to the Analysis phase, the main features of the Synthesis phase are similar for the two professions, however, once again they different in description and some of the suggested activities. In addition, there also seem to be other differences, discussed in Chapter 5.2.2. - 5.2.6.

*The differences*

The differences between the two professions in the Synthesis phase, found in this thesis are:

- Focus in the description
- Suggested activities to generate solutions
- Choice of concept
- Creativity
- Use of previous examples
- Use of analogies
- Sub-solutions

*Focus and activities*

As discussed in both chapter 4.6 and 5.1.4 there seem to be a *difference in focus* in the two professions approaches. The engineering approaches describe different phases in the projects design process and states different goals for each phase, while architectural approaches describe features and ways to think.

In the engineering approaches, several *activities* are suggested to be carried out in order to find possible solutions. Some activities are more technical, suggesting the use of charts, matrices etc., such as the morphological box, and some are more intuitive, such as the use of analogies or brainstorming. Architectural approaches seem more careful to suggest specific activities. They rather describe different phenomena and guidelines concerning finding solutions. One main part of the synthesis for architects seems to be the primary generator, or the concept.

Why this difference in suggested activities exists may depend on different reasons. One may be that the architects receive training in school to find their own design approach, and thereby learn different types of activities and skills to use to generate suggestions. In contrast, engineering student seem to receive less education in designing, and thereby needs more guidance on what to do in the design process as well as what activities to use in order to reach the goal.

*Choice of concept*

Both professions seem to use concepts in their design process when searching for solutions, however, there appear to be a difference in the choice of concept. Engineers seem more prone to choose concepts that represent structural principles while architects appear to use concept in a wider, and maybe more diffuse way.

Since concepts are used by both professions, but in seemingly different ways, there may be a risk of confusion when collaborating together.

*Creativity*

Both professions seem to believe that creativity is an important part to generating solutions, and it seems as if they share a common definition of creativity. Lawson says that the type of creativity used for the two professions may differ; architects need to have a highly developed visual sense while engineers need more numerical skills in order to achieve their design goals (Lawson, 2006).

As Lawson suggest, the type of creativity may differ between the two professions. However, this is perhaps a positive thing in the collaboration, that the two sides offer different types of creativity that can complete each other. The difficulty may lie in knowing how to collaborate in an optimal manner. An important aspect to creativity, as both professions mentions, is to not be prejudiced in the creativity. This is especially important in the collaboration between the professions so that everyone dares to express their ideas.

*Use of previous examples*

Engineering and architectural authors seem to agree that experience and old examples are an important part in designing. However, there seem to be a difference in the actual execution and focus of the activity. Similar to the concept, engineers appear to focus more on using previously known structural principles while architects seem more prone to find inspiration or a certain expression.

The differences in the use of previous examples may also originate in the education. Architectural students are encouraged to find inspiration in other's work, but still create a new and own project. Engineering students are not as trained in designing, as stated before, and if given an exercise, it is usually a predesigned element that should be dimensioned, not an own design. This may lead to the engineering students not developing an ambition to create something new and own, since they are not encouraged to. However, maybe it is not as easy for engineers, especially students, to create "new and own" structural principles since this will demand a high understanding and experience in structural behaviour.

*Use of analogies*

Another difference between the two professions seems to be the use of analogies. Once again, engineers seem more technical, while architects seem more abstract in their use of analogies.

Analogies can be very helpful to describe complex things and increase the understanding of what is really explained or strived for without having to put it into words. Since design ideas can sometimes be hard to convey, and perhaps even harder to be understood between different professions, analogies may give the opportunity of an increased understanding of the idea. However, at the same time there is a risk of increasing the gap between the professions if the analogy is too far-fetched or if the two professions do not share the same language.

*Sub-solutions*

Similar to the engineers wanting to divide the design requirements into overall function and sub-functions, they also seem positive to divide the design solution into sub-solutions. They believe this will make the design problem less complex and easier to handle. In contrast, architects seem to reject the division into sub-solutions, since they believe there might be a risk of loosing the entirety of the project if each part is solved on its own.

Perhaps the engineers need to divide the project into smaller parts is due to their calculation procedure, where all the different parts need to be calculated on their own, not just the entirety. However, in the overall design process, where the two professions are supposed to collaborate, they need to share a common view on how to proceed.

## 5.3 Evaluation

Evaluation Phase is where the various suggestions from the Synthesis Phase are critically evaluated against the objectives identified in the Analysis Phase.

### 5.3.1 Different Evaluation approaches

#### 5.3.1.1 Different evaluation approaches, engineering

Below follows activities in the *Evaluation Phase,* described by engineering approaches.

**Kroll et al.**

***Overview and aim***

Within the *Parameter Analysis* loop is Kroll et al.'s step called *Evaluation*. In this step of the loop, the designer must consider to what degree the physical realization created in *CS* is a possible solution to the entire problem. The activities used when evaluating are: *comparison of the configuration to the original requirements, identification of weaknesses* and *comparison between several configurations.*

***The activities***

In the first activity, *comparison of the configuration to the original requirements*, the different suggestions are compared to the requirements found in the Analysis Phase. The second activity, *identification of weaknesses,* aims at finding weaknesses within each suggestion, and in the last activity, *comparison between several configurations*, the different suggestions should be compared to each other.

Kroll et al. mentions the importance of having non-working solutions in the creative process as well, since they can inspire similar but more suitable solutions and give stimulation to the creative process.

It is emphasised that if the designer is not happy with the results after the evaluation, the loop should continue. It may also be necessary to go even further back in the process (Kroll et al., 2001).

**Pahl et al.**

***Overview and aim***

The second part of Pahl et al.'s *Conceptual Design Phase*, is comparable to the Evaluation Phase. In the second part, the different working solutions found in the previous steps are evaluated in order to find the most suitable solution. The evaluation is performed by using an *Evaluation Matrix*.

### *The activities*

Firstly, evaluation criteria are identified based on the requirements list and rated in their order of importance. All evaluation criteria are given a weight factor, and a grading scale is determined. The grading scales, or value scales, will consist of a defined set of number to be used when determining grades for different sub-solutions. The scale can be from 0-10 or 0-4, as seen in Figure 5.22, where every value has specific criteria.

| Value scale | | | |
|---|---|---|---|
| Use-value analysis | | Guideline VDI 2225 | |
| Pts. | Meaning | Pts. | Meaning |
| 0 | absolutely useless solution | 0 | unsatisfactory |
| 1 | very inadequate solution | | |
| 2 | weak solution | 1 | just tolerable |
| 3 | tolerable solution | | |
| 4 | adequate solution | 2 | adequate |
| 5 | satisfactory solution | | |
| 6 | good solution with few drawbacks | 3 | good |
| 7 | good solution | | |
| 8 | very good solution | 4 | very good (ideal) |
| 9 | solution exceeding the requirement | | |
| 10 | ideal solution | | |

*Figure 5.22 Value scale by Pahl et al. (Pahl et al., 2007)*

Thereafter, every working solution is given a grade, based on the chosen value scale, of how much they fulfil the criteria. Example can be seen in Figure 5.23.

| Evaluation matrix | Shape and form | Bridge fitting into the landscape | Production technique | Innovative design | Construction time | Building costs | Maintenance costs | Impact during construction | Impact during lifetime | Grade average |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of criterion | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| *Relative weights of criteria* | *0.16* | *0.16* | *0.06* | *0.08* | *0.06* | *0.09* | *0.09* | *0.15* | *0.16* | ***1.0*** |
| Double Arch (H section) | 2 | 4 | 2 | 2 | 3 | 3 | 2 | 3 | 2 | **2.6** |
| Double arch (A section) | 4 | 4 | 1 | 3 | 1 | 2 | 2 | 3 | 2 | **2.7** |
| One pier | 3 | 1 | 2 | 3 | 3 | 3 | 2 | 2 | 2 | **2.2** |
| Two piers (H section) | 1 | 1 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | **1.8** |
| Two piers (A section) | 4 | 1 | 2 | 3 | 1 | 2 | 2 | 2 | 2 | **2.2** |

| | |
|---|---|
| 0 | Unsatisfactory |
| 1 | Just tolerable |
| 2 | Adequate |
| 3 | Good |
| 4 | Very good |

*Figure 5.23 Example of Evaluation matrix (Niemeyer, 2003)*

A grade average is then calculated for every overall solution by adding the scores from all different criteria and multiplying these with the weight factor. This grade value determines the quality of the overall solution, which can then be compared with the other solutions grade averages to find the most suitable suggestion. The evaluation uncertainties must also be estimated to make sure that the chosen decision is actually the most suitable, not just a result of the number-process (Pahl et al., 2007).

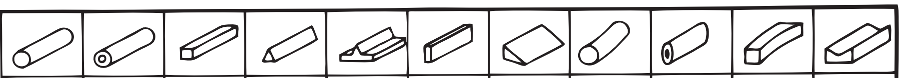
## Stuart Pugh

### *Overview and aim*

The second main component in Pugh's step *Concept* covers the evaluation of generated solutions and the selection of the solution that meets the PDS the most. When evaluating, a combination of *evaluation matrix* and *controlled convergence* is used (Pugh, 1991).

### *The activities*

In the *Evaluation Matrix* (see Figure 5.24), similar to Pahl et al., all concepts are placed in the top horizontal row, and the different criteria are placed in the first vertical row. Every concept will then be given a score of how well they accommodate every criterion. Each concept's score is summed up, and the different concepts' scores can be compared. Weak concepts are eliminated and strong concepts are improved if lacking in certain areas. When the evaluation is done, the strongest suggestion should be chosen.



| Criteria \ Concept | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | + | − | + | − | + | − | D | − | + | + | + |
| B | + | S | + | S | − | − | | + | − | + | − |
| C | − | + | − | − | S | S | A | + | S | − | − |
| D | − | + | + | − | S | + | | S | − | − | S |
| E | + | − | + | − | S | + | T | S | + | + | + |
| F | − | − | S | + | + | − | | + | − | + | S |
| Σ+ | 3 | 2 | 4 | 1 | 2 | 2 | U | 3 | 2 | 4 | 2 |
| Σ− | 3 | 3 | 1 | 4 | 1 | 3 | | 1 | 3 | 2 | 2 |
| ΣS | 0 | 1 | 1 | 1 | 3 | 1 | M | | 1 | 0 | 2 |

*Figure 5.24 Pugh’s evaluation matrix (Pugh, 1991)*

*Controlled convergence* (see Figure 5.25) is used in combination with the evaluation matrix. Through controlled convergence, concepts are evaluated and eliminated though the evaluation matrix. At the same time, this method allows new concepts to emerge though new concept generations, CG. The aim is that through several concept generations and eliminations, controlled convergence will lead to one solution being chosen as the final solution (Pugh, 1991).

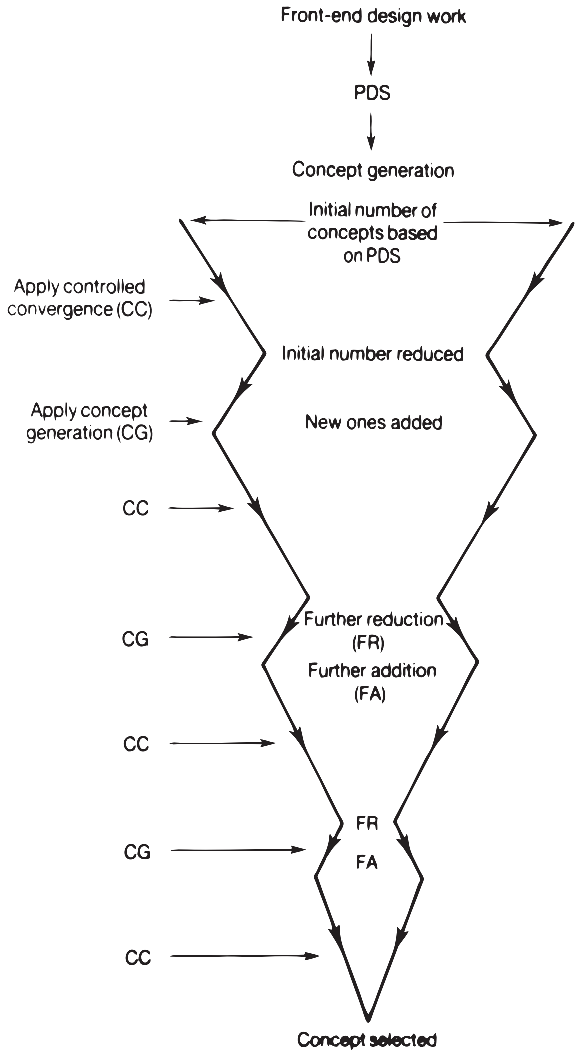



*Figure 5.25 Controlled convergence (Pugh, 1991)*

#### 5.3.1.2 Different evaluation approaches, architecture

Below follows activities in the *Evaluation Phase,* described by architectural approaches.

**Bryan Lawson**

***Overview and aim***

Lawson's *Evaluating* describes skills designers need to possess in order to regulate and select appropriate moves. The skills in the *Evaluating* group are: *Objective and subjective evaluations* and *Suspending judgement* (Lawson, 2006).

***The activities and skills***

In *Objective and subjective evaluations,* Lawson discusses that designers must be able to develop suggestions based on different choices they have made, and must also be able to know when to stop generating suggestions. They must have the ability to evaluate their proposals, which can be done by evaluating against different criteria and seeing how well a solution matches that criteria. However, all criteria cannot be measured and therefore the designers need to make own judgement of how suitable a solution is. The evaluation must be both objective and subjective.

Designers must also be able to *suspend judgement* to be able to form creative thoughts and ideas without worrying about being criticised (Lawson, 2006).

**Jerker Lundequist**

***Overview and aim***

Two of Lundequist's sub-processes can be said to belong in the Evaluation Phase: *Artistic* and *Negotiation and Decisions* sub-processes. The *artistic* contains discussions about aesthetic and ethical points of view, while the *negotiation and decision process* handles different decisions concerning the product by discussion between the participants involved in the specific problem at hand.

***The activities***

Within the *artistic sub-process*, the suggestions presented are discussed and judged by the project team. The goal is to have a rational argumentation where different motives are weighed against each other. In design, Lundequist claims there is no right or wrong, it is rather a question of good or bad. Arguments to support one side or the other should be backed up by a rational system of criteria (Lundequist, 1998).

The *negotiation and decision sub-process* also cover the weighting of different motives, however these motives are less concerned with the esthetical and ethical aspects, as in the artistic process, and more concerned with characteristics of the product. Specialists, users, clients and authorities all take part in the discussion before a decision is made (Lundequist, 1998).

#### 5.3.1.3 Different evaluation approaches, multidisciplinary

Below follows activities in the *Evaluation Phase,* described by multidisciplinary approaches.

**Cecil Balmond**

***Overview and aim***

Since Balmond's work is not an official design approach, it is hard to see a clear evaluation process. However, his work has been interpreted to find the evaluative aspects, and he seems to evaluate all parts in accordance to his visions and concept for the whole building.

***The activities***

The main activity for evaluating is the comparison of the solutions with his own goals and vision to determine if the suggestion meets the requirements, or if any aspect needs to be improved. This involves calculations for evaluating if the main part of the structural system that affects the overall appearance is acceptable. The chosen structural system is compared to both the initial concept as well as the requirements. They also evaluate the cost of the project and, as in this project, if the budget is exceeded, changes are made and evaluated again to make sure they are in line with the concept.

If he believes the solution is satisfactory, the suggestion is developed further into detail. If not, the problem probably needs to be rephrased or seen in a different manner (Balmond, 2007).

<u>**Nigel Cross**</u>

***Overview and aim***

When various design solutions have been generated, the designer needs to evaluate and choose the most appropriate solutions. The decisions can be made by intuition, experience or by arbitrary decision, however, Cross recommends a more rational or open procedure. Cross therefore suggests two activities to be used, *Evaluating alternatives* and *Improving details* (Cross, 2000).

***The activities***

Cross suggests using a *Weighted objectives method,* similar to Pahl et al. and Pugh's evaluation method, also called evaluation matrix. All aspects need to be evaluated and given a grade, and since the various criteria do not have the same weight, some sort of weighting needs to be used in addition to the matrix.

Lastly, *Improving details* is performed to increase or maintain the value of the project while trying to lessen the production costs (Cross, 2000).

### 5.3.2 Criteria in the evaluation

*Evaluation criteria*

When evaluating, all approaches evaluate and compare the different suggestions against some criteria. For the engineering approaches, the evaluation criteria are often what is described in the requirements list, brief or PDS created in the analysis. These lists, as described in Chapter 5.1 contains a variety of categories that the design should fulfil. The architects also evaluate against different criteria, however, they seem to create own motives based on the brief and evaluate the suggestions against these motives and vision for the project. In difference to the engineers, they do not seem to have such an explicit list of evaluation criteria.

*Economy in the evaluation*

Basically all building projects will have a budget. However, in the approaches, the opinion differs on when and how much economy should affect and be a part of the design process. However, it is mainly in the evaluation the economy and the budget is mentioned, if even at all.

One of the approaches where economy is given much focus is Pahl et al.'s approach. This is very apparent, especially in their evaluation phase, where both technical and economic characteristics should be judged. They believe that economy should be taken into consideration in all steps of the approach; however, sometimes it is not possible to be able to give the cost in figures, as for example in the early concept phase (Pahl et al., 2007). Kroll et al. mentions the importance of economy and the cooperation with finance throughout the process. However, how economy should be taken into consideration in the approach or in the evaluation is not discussed further (Kroll et al.).

Lawson discusses one limitation with making judgements based on economy in the evaluation. He believes a common scale of measurement may not be very suitable in all design problems, and even though economy should be taken into consideration, all aspects cannot be judged simply based on economy (Lawson, 2006).

However, if economy is taken into consideration too late into the process, the design proposal may be forced to undergo undesirable changes. This could be seen in process, where economy is not acknowledged until the later stages of the process. The team then realise that they were over budget and some key features had to be redesigned (Balmond, 2007).

Cuff's discusses going over the budget in one of her dialectic. She believes that exceeding the set out limit is often something positive in the building industry. By exceeding the limit, and thereby often also the budget, the chance of the building going beyond what was initially planned and becoming an excellent building increases (Cuff, 1998).

Even though the authors cannot be said to represent the two professions as a whole, they show that engineers are more prone to taking economy into consideration during the evaluation and as a part of the process than the architects seem to be.

### 5.3.3 Evaluating with or without numbers

Evaluating is an important part in the design process, and evaluative decisions needs to be taken all throughout the process. Since design problems can be complex and usually have no right or wrong solution, the process of evaluating may be very problematic. Different approaches are suggested for how to take decisions and to evaluate suggestions; however, these approaches differ and some recommend to evaluate with numbers and percentages while other rely more on value judgements.

*Evaluate with numbers*

Both Pahl et al. and Pugh suggests evaluating with numbers. Pahl et al. suggests a method where the different solutions are given grades on how well the meet the requirements. These grades are then combined to form a total value that will indicate how appropriate the suggested solution is (Pahl et al., 2007). Pugh suggests a similar evaluation with numbers and weight factors, using an evaluation matrix (Pugh, 1991). In addition, Pahl et al. mention that the designer need to make sure that the chosen suggestion with the highest score is actually the most suitable, not just a result of the number-process (Pahl et al., 2007). However, how this decision is made is not further described.

In contrast to this, Lawson claims it is not reasonable for designers to use some method or process that will protect them against making judgement and taking decisions in the design process. Since design problems often are quite fuzzy and indefinable, designers are often tempted to find measurable criteria that can decide if the suggestion is satisfactory or not. In design, both quality and quantity is measures. Quantity is often described using a numerical system. Quality on the other hand may be harder, maybe even impossible, to be described by numbers. Since many factors in design cannot be measured and valued nor be compared to each other, it is therefore more important for a designer to have the knowledge and feel for the design problem. The designer should take strategic decisions and know what kind of changes will give rise to what results, rather than relying on careful calculations (Lawson, 2006).

*Without numbers*

Instead Lawson believes that value judgements in design are inescapable due to the fact that there are many different variables to take into consideration and that they cannot be measured in the same way or even measured at all. Neither is there a proper way to decide what part of the problem is more important, or which solutions is the most satisfactory, and therefore the designer must make own decisions during the process (Lawson, 2006).

A risk with value judgements in design is that the designer tends to be subjective when evaluating. It is hard for designers to be dispatched, and the designers are often very protective and possessive about their solutions. However, experienced designers should be professional enough to base their decisions on justified opinions (Lawson, 2006).

Lundequist agrees with Lawson, and clearly states his belief that aesthetical and ethical decisions in design only can be taken through rational discussions between the concerned parties (Lundequist, 1998). Further, since the decisions made by designers will affect the lives of many people, the judgements cannot be made in private. Those types of large-scaled design processes must invite all those who will be affected to participate (Lawson, 2006).

There seems to be a difference in the attitude towards evaluation, whether to base decisions mainly on numbers or value decisions. However, no clear statements exist from either side that if preferring to evaluate with numbers, the designer will automatically take no value decisions. This simply shows the tendency for engineers to be more comfortable using matrices and numbers.

### 5.3.4 Discussion Evaluation

In the Evaluation Phase, once again the two professions differ in their description as well as in some of their suggested activities.

The main difference between the two professions is whether or not to *evaluate using numbers.* Another difference is what *criteria* the evaluation should be based on or take into consideration, and to what extent, should influence the evaluation.

*Criteria for evaluation*

Both professions use different criteria in their evaluation, however, there seem to be a difference in the type of criteria used. Engineers seem more prone to strict and clearly defined criteria, and perhaps even criteria that can be measured or expressed in numbers. Architects seem more focused to make sure that the projects concept and visions are fully accomplished and still in line with the brief.

One criterion that appears to be given different focus for the two professions is economy. It seems as if engineers are more prone to taking economy into consideration during the evaluation and as a part of the design process than the architects seem to be.

What types of criteria the different suggestions are evaluated against will obviously affect the result and the chosen solution. If important criteria are ignored, such as economy, during the process, there is a risk of having to make large changes to the design to satisfy the ignored criteria, which may jeopardize the concept and design of the project.

Another aspect that affects the process is if evaluation is a continuous procedure or if it is only performed after the Synthesis when a sufficient number of solutions are found. Engineers seem more prone to think of evaluation as a step performed after the synthesis, while architects seem to consider evaluation as an on-going process during their synthesis. Similarly to ignoring certain criteria, evaluating only in the end may lead to unwanted changes in the design to fulfil the desired criteria.

*Evaluate using numbers*

In the different approaches, the engineers seem to suggest evaluation activities where the different suggestions are evaluated using grades and weight functions. The architects no not share this view, and rather suggest that evaluation should be based on rational conversations and value judgements.

There is a risk of using number evaluations in designing, since numbers and percentages may not always portray the best suggestion. It is an important part of being a designer to know how to take evaluative decisions and what they should be based on. However, no clear statements exist that if preferring to evaluate with numbers, the designer will automatically take no value decisions. A positive aspect to using numbers while evaluating is that, most often, most criteria are taken into consideration and that the decisions may be less subjective.

There is no evaluation method that is proven to be better than the other. Perhaps the most important thing is to be aware of the method used and its risks. However, in collaboration, it might be necessary to share a common evaluation method as well as common evaluation criteria in order to be more successful.

## 5.4 Tools and representations

Design solutions can be represented in many different ways: sketches and drawings, writings, models and computer drawings and simulations. Lawson describes representing ideas and suggestions in drawings, text, diagrams etc. as an important skill that designers need to have. These representations can be seen as central inputs to the design process that the designer can have conversations around, and not just as visual output (Lawson, 2006).

With the help of these different tools, each individual will portray the design in his own individual view and the respective representations will depict their view on the design. Different designers also choose to work within different object worlds represented in technical lists, system of symbols, metaphors, models etc. (Bucciarelli, 1998).

Further, there is a risk of working in these object worlds, since the model is just a reflection of the designer's intentions, and not what it will actually look like if constructed. It is therefore important to know how well the representation actually does represent the reality by investigating the reliability of the representation's relevance to its purpose (Lundequist, 1998).

In addition, Lawson suggest how to minimize this problem by working with multiple representations. By mixing different representations, the design proposition can be tested and developed to avoid errors and risks. A designer should be able to choose from the representations, to choose those who represent the case most accurately as not to give a false image of the proposal (Lawson, 2006).

Since different designers will probably use different representations and work in different object worlds their representations can complete each other and be more reliable, if the different designer work successfully together. However, since their respective tools and representations will mirror their expertise and background and therefore will differ, and maybe even be hard to comprehend for the other profession, it is important that both professions are as clear as possible in their representations to prevent misunderstandings.

# 6 Comparison of the two professions in the design process and possible improvements

From the history of design theory, the two professions once shared a view of the design process, but now their views seem to have separated. What they still do have in common is three main phases, Analysis, Synthesis and Evaluation, which the two professions seem to agree on their basic features. However, when these phases should be performed and how differs, as well as how they are described seem to differ.

These differences were found in the previous chapters 2 to 5, and are summarized in respective discussion-chapter. Many of the differences reoccur throughout the chapters as well as their originating reason, and can be seen as overall differences. These overall differences will be discussed below, and possible improvements will be suggested.

*The overall differences*

The main overall differences can be summarized into the following categories:

- Difference in focus of description
- The structure of the approach
- Suggested activities

The two professions seem to have a difference in focus while describing the design process. Firstly, they seem to disagree whether or not a step-wise method should be described: engineers seem positive to step-wise approaches while architects seem to reject this type of descriptions. Further, the engineering models emphasize the projects expected stages and their sequence, while architecture models are more focused on the cognitive processes that are necessary in the design process.

The different described models also appear to have a difference in structure. Engineering models have a more linear and sequential nature while the architectural models have a more spiral and cyclical nature. Engineers seem to consider the phases Analysis, Synthesis and Evaluation to be separate phases succeeding each other in the design process, while architects appear to be of the opinion that these three phases overlap and interact with each other. There also seem to be a disagreement on whether a design problem can be broken down into sub-problems and sub-solutions: engineers see this as a well-functioning method, while architects do not discuss the design problem in these terms.

The last main overall difference is the suggested activities. These activities were clearly present in the engineering approaches, while concrete activities rarely were mentioned by the architectural approaches. Some of the suggested activities by the two professions were rather similar while some activities were altogether different. The activities used by the engineers seem to be more technical in their nature; they often suggest activities containing lists, matrices, diagrams, etc. The activities that could be found or interpreted in the architect’s approaches may be conceived as more abstract and diffuse.

*Why these differences may exist*

As described, there are some differences between the two professions approaches. Why they exist can depend on different reasons, some of them more straightforward than others. These reasons discussed in this thesis are:

- Knowledge domain, experience and expertise
- Type of task: well-defined or ill-defined
- Education: science and problem focused or arts and solution focused
- Culture: opinions, prejudices and use of language.

One main and straightforward reason is that the two professions knowledge domains are different. Engineers can rely on science, while architects lack the equivalent science, which may make them having to rely more on trial and error. The differences in experience and expertise will also affect the understanding of a design problem and consequently how it is solved.

Another reason may be that the two professions have different types of tasks and design problems; architects mainly view the design problems as ill defined when engineers seem to view them as well defined. Therefore, even though they can work within the same project, it is very likely the two professions will work with different strategies solving the different problem.

Some of the differences may originate in the two professions education. Engineers have a more science-based and problem-focused education while architects have a more arts-based and solution-focused education. In addition, both in education and at offices, cultures are developed for the two professions perhaps resulting in different opinions, prejudices and use of language.

Although several differences and reasons exist, they do not necessarily have to be interpreted as something that will complicate the process. Since the two professions actually are separate professions with different expertise and purposes, they are supposed to be different. What are important in their work is that they understand and trust each other and that their collaboration is successful in order for their work to complete each other’s. To be able to fully understand each other in the design process, some improvements may have to be carried out.

*Possible improvements*

Although differences between the two professions exist in their approach in the design process, many practising engineers and architects seem to think that the collaboration between them works satisfactory. However, if some improvements in the design process were carried out, the possibility of even better collaboration could increase, perhaps leading to a more effective design process where both money and time could be saved. In addition, if the two professions were more interconnected in their work, perhaps the design can reach even further.

As stated above, the understanding of each other’s work as well as way of working should improve. By knowing the background of the other profession, their approaches, choices and motives might be clearer and thereby misinterpretations and prejudices can be avoided.

Understanding of the other profession should start to be developed during the education. Of course, the two professions require a different and separate education, however, they might gain by working together in an early stage. Perhaps they can work together to solve a design task, where both expertise's are used and interconnected. For example, a kind of role-play could be carried out where different students receive different tasks, such as architect, engineer, contractor, management etc.

Another possible improvement is for designers to be more aware of design approaches and design theory. If a designer, engineer or architect, knows their own design approach they can be more aware of what choices they make and why. Thereby the designer can be more conscious of the possible risks and limitations with their approach, and it may also be easier for them to improve their own approach. This could be executed both during respective education as well as for the practising designer.

Something that both professions' approaches lacked is their description of a team design process; most approaches describe a single individuals approach. It is of course necessary for the individual designer to find an approach they are satisfied with, however, all individual approaches must be adapted in to a bigger collaborative approach. This collaborative approach seem to have been forgotten, or perhaps is too complicated to be described, however, if such an approach were to be described, perhaps the cooperation between the two professions could improve.

# 7 Conclusion

In this thesis different design approaches aimed towards structural engineers and architects have been studied and compared in order to find similarities and differences between them. The different approaches were divided into four different categories depending on the authors' professions and whom their approach was aimed at. In total, 3 engineering approaches, 3 architectural approaches, 2 multidisciplinary approaches and 2 organizational approaches have been studied.

All approaches have been described in different scales: general view, main features and activities. This was performed with the intent to illustrate the similarities and differences between the two professions more explicit. By finding similarities and differences, the understanding of each other's approaches can increase and possibly gain their collaborative design process.

The overall similarities found in this thesis between the two professions were their main phases that seem to contain the same features although they may differ in terms and description. These main phases were summarized into Analysis, Synthesis and Evaluation in this thesis and have been described more in detail.

The overall differences found were the focus in the description of the approaches, their structure as well as suggested activities. The difference in focus varied in terms of either describing a step-wise method and thereby focusing on the projects different stages, or describing a phenomenon with general guidelines that concentrates more on the cognitive process of designing. The structure of the two professions approaches seems to be either linear and sequential, or more spiral and cyclical. The approaches also differed in some of their suggested activities within their phases and how they were suggested to be performed.

The reasons for these differences may depend on different reasons: knowledge domain, experience and expertise as well as the type of task, education and culture. However, some of these differences are obvious and necessary since the two professions need to fulfil different purposes; some of these differences may enrich the cooperation while some can complicate it.

To avoid some of the possible complications, a few improvements were suggested. The foundation for the suggested improvements is an increased understanding for the other professions approach, knowledge and background. To be able to do this, the cooperation is suggested to start already during the education. In addition, better knowledge about design theory and design approaches may increase the understanding of each other's profession as well as make it easier to unite the two professions into a joined design approach.

# 8 Further work

In this thesis, 10 different approaches have been described and compared. To receive a more quantitative comparison, more design approaches can be studied.

This thesis has focused on describing different approaches indented for structural engineers and architects and finding similarities and differences between them. Further work could concentrate on finding more information on how and if these similarities and differences actually affects the cooperating in practice. If finding how the cooperation is affected, possible improvements can be investigated.

Since this study is based only on theoretical approaches, it may be interesting to find approaches used in practice and to compare these.

Lastly, since this thesis mainly focuses on the respective professions different approaches; further work could study integrated approaches.

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# A. Appendix: Used sources in this study, presentation of the authors

Below follows a description of the authors used as the main sources for this study. The intention is to clarify their background and intentions in order to better understand their perspective of the design process.

In this chapter, authors will be divided into different categories depending on their profession. This may be a rather crude division, however, it is done to hopefully increase the understanding for the reader.

## A.1 Engineering authors

**<u>Kroll et al.</u>**

***The author***

*Innovative Conceptual Design – Theory and Application of Parameter Analysis* is written in 2001 by the authors E. Kroll, S.S. Condoor and D.G. Jansson. They are all three engineers, working as teachers and professors.

E. Kroll is a teacher at the faculty of Mechanical Engineer Department at Ort Braude Collage in Karmiel in Israel and his areas of interest include design theory and methodology; design for manufacturing, assembly, and disassembly; and automatic assembly planning.

S.S. Condoor is a professor in the Department of Aerospace and Mechanical Engineering at Saint Louis University and working with product design, design for manufacturing, and computer-aided design.

D.G. Jansson is the principal in David G. Jansson & Associates, a consultation company. He was previously a professor and director of the Innovation Centre at the MIT and a professor, founder, and director of the Institute for Innovation and Design in Engineering at Texas A&M University (Kroll et al., 2001).

***The book***

The book describes a general method in the early stages of the design process. It is aiming to lead the user through the design process, trying to identify critical issues and propose configuration-specific solutions to these issues, using innovation as a foundation. They describe it as a useful text for advanced undergraduate and graduate students, as well as a handy reference for practicing engineers, architects, and product development managers.

Kroll et al. define the content of their book as a methodology that should lead the user through the design process. They divide the methodology into several different steps, all thoroughly described (Kroll et al., 2001).

***Relevance for this study***

Kroll et al. are mentioned in design theory as describing a design approach for engineers. *Innovative Conceptual Design – Theory and Application of Parameter*

*Analysis* is also used as a core reference in several master theses, carried out at the Division of Structural Engineering at Chalmers.

## Pahl et al.

***The author***

*Engineering Design – A Systematic Approach* is originally written by G. Pahl and W. Beitz. Just before the current editions, Beitz passed away and Pahl received help with his work from J. Feldhusen and K.H. Grote.

G. Pahl is a mechanical engineer. Early in his career he worked at Brown Boveri Company, as a commissioning engineer for large steam turbines and compressors. After 10 years he became a professor for machinery components and design principles at the university in Darmstadt. He has been vice president for The German Research Foundation 1978-84.

W. Beitz was a mechanical engineer at Technical University Berlin where he thought Mechanical Design. He has also worked for seven years as a design engineer at AEG-Telefunken Berlin.

J. Feldhusen worked as senior designer in the automotive industry and is now a teacher at RWTH Aachen University, and K-H. Grote is a professor in the US, where he teaches design and running projects (Pahl et al., 2007).

***The book***

*Engineering Design – A Systematic Approach* is a general description of the early stages in the product design process. They strive towards breaking the process down into different phases, into specific steps, and to describe the activities within these steps. They wish to structure the design process, to know what happens and when. The aim is to provide guidance to successful product design, both for practicing designers, students and teachers within the design field. For students, it can be used for educational purposes for them to quickly become accustomed to design practice. Their thought is that the book should be very general and be able to be used in all types of design. (Pahl et. al., 2007)

***Relevance for this study***

Pahl et al. are mentioned as representing a design approach for engineers that is based on VDI's design approach. *Engineering Design – A Systematic Approach* is, like Kroll et al., a source for information about the design process used in several master theses for the Division of Structural Engineering at Chalmers.

## Stuart Pugh

***The author***

Pugh was a design engineer and manager, with a degree in Mechanical Engineering. In his early career he worked as a project engineer, but left the industry in 1970 and began his academic career. His main achievement in the design field is his book *Total Design: Integrated Methods for Successful Product Engineering.* His theories where introduced and taught both to students of engineering, architecture, industrial managers and law (Wikipedia, 2013a)

***The book***

The book's aim is to describe design as a systematic and disciplined process, based around a core of design activities. Pugh's work is based on his theory of total design, that total design is a necessary systematic activity that involves product, process, people and organization. According to this, his proposed model can be used by students and practitioners in engineering, architecture, product design and computer science (Pugh, 1991).

***Relevance for this study***

Pugh is mentioned as one of the better-known authors within design theory. He presents a model based on his view, total design, which can be interesting when comparing different approaches between the professions. His approach is according to himself applicable for all design professions, however, Roozenburg et al. mentions his approach as an engineering approach.

## A.2 Architectural authors

**Bryan Lawson**

***The author***

Bryan Lawson is a psychologist, architect and design researcher who has written many books on the nature of design processes.

***The book***

Bryan Lawson's book, How Designers Think, is based on 40 years of research that is based on observations of designers at work and interviews with designers, clients and collaborators. He tries to understand and describe how designers think, and explores the professions education, skills, tasks and techniques. The aim is to give helpful advice in order to obtain a better understanding for design, however, he clearly states that the book is not intended to give authoritative prescriptions on how a design process should be performed (Lawson, 2006).

***Relevance for this study***

Lawson is a commonly used source in design theory, both for his own opinions as well as his discussions about others' approaches.

**Jerker Lundequist**

***The author***

Lundequist is an architect and a professor in design methodology. He has taught and researched at both Chalmers and KTH in Sweden, as well as Edinburgh Computer

Aided Architectural Design Group. His area of expertise is design and product development, mainly adapted to the building sectors' information technology (Lundequist, 1995).

***The book***

Lundequist's book *Projekteringens teori och metod – en introduction till designteori* is about design theory and how it is treated within all fields of design and product development. He describes the history of design theory, as well as about the design process and its features (Lundequist, 1998).

***Relevance for this study***

Lundequist was recommended by the architecture department at Chalmers as an important source for descriptions of the design process.

**Dana Cuff**

***The author***

Cuff is a professor in the Department of Architecture at UCLA in the US and has a Ph.D. in architecture and a bachelor in psychology and design. She is also an author, has published several books and is the founding director of a research centre called cityLAB at UCLA that examines modern cities and its challenges (UCLA, 2013).

***The book***

Her book *Architecture: The story of practice* was published in 1991. Her goal was to describe what actually happens in an architect´s practice, what the architect's professional activities are and how they usually are performed. Her book is based on research in architectural offices, followed the work and meeting of architects at different firms for six months. She has also interviewed several architects, clients, programing specialists etc.

This book was one of the first to write about observations from within architectural practices and to describe the process behind designing buildings, not just the end result as many have studied before. The book is written for those who are a part of the design process: architects, clients, politicians, engineers, citizen design boards, and planners. Dana Cuff hopes this book will give new understanding of the design process and that it will be helpful in the future work of creating architecture (Cuff, 1998)

***Relevance for this study***

Cuff was recommended by the architecture department at Chalmers as an important source for descriptions of the design process.

## A.3 Multidisciplinary authors

<u>**Cecil Balmond**</u>

***The author***

Cecil Balmond is an educated and well-established engineer, working with Over Arup and Partners for over 30 years. He has an unconventional approach that originates in his interests in the genesis of form and the overlap of science and art (Balmond, 2007) He has his own architectural practice, Balmond Studio, which he founded in 2010. The practice focuses their work on research, mainly within art, architecture, design and consulting (Balmondstudio, 2013).

***The book***

The book is a collection of Cecil Balmond's thoughts and drawings from some of his past projects. The setup is very similar to that of a diary, where the progress is described from recollections of important moments and key events. The book shows the works of Cecil Balmond and his process that formed the final building. The book is build up by sketches and diagrams, tied together with thoughts, ideas, keywords and explanations. It shows how Balmond explores more than just the obvious, how he plays with concepts and keywords together with analogue thinking (Balmond, 2007)

***Relevance for this study***

Cecil Balmond represents the category of descriptions where a well-known designer's process is documented. He is also relevant since he has a conventional way of working and can be said to represent Total Design.

<u>**Nigel Cross**</u>

***The author***

Nigel Cross is both Professor of Design Studies and Professor of Design Methodology. He has, since the 1960s, researched and taught design methodology and computer aided design (Cross, 1992). He is one of the main profiles in design research and in writing about issues relating to design and the design process (Wikipedia, 2013b). He has a B.Sc. in Architecture, a M.Sc. in Industrial Design Technology and a Ph.D. in Computer Aided Design.

***The book***

Cross's book *Engineering Design Methods* was first published in 1989 and offers a strategic approach for designing. It is primarily intended for engineering and industrial design, however it can be relevant for all design fields. The approach suggested in the book is a hybrid of recent approaches that combines both the procedural and the structural aspects in the design process (Cross, 2000).

***Relevance for this study***

As one of the big names in design theory and with a long experience within the design research field, Nigel Cross is interesting for this study. The approach mentioned in his book is an attempt at creating an integrated model for the design process which can be used by both engineers and architects.

## A.4 Organisations, both Eng. and Arch. organisations

**Architectural organisation RIBA**

***The organisation***

RIBA means The Royal Institute of British Architects. It was started in 1834 by several well-established architects, and was in 1837 acknowledged royally. Today RIBA is a membership organisation consisting of 44000 architects and they support their members by providing standards, training and support, and see themselves as a collective voice for architecture (RIBA, 2013b)

***The Plan of Work***

In 1963 RIBA began to develop the RIBA Plan of Work, with the aim for it to be a UK model for the building design and construction process. The intention was that its framework should serve architects, but also other professions in the construction industry as well. The Plan of work has been developed several times to reflect the developments in design over the years. The latest Plan of Work was constructed 2013, where a design process made up from steps A-L where changed to eight steps, 0-7 (RIBA, 2013a).

***Relevance for this study***

In this study, RIBA represents an architectural organization that describes the design process.

**Engineering organisation FIB**

***The organisation***

FIB, the International Federation for Structural Concrete is an association created in 1998 from the merger of CEB and FIP. Their objectives are to advance the technical, economic, aesthetic and environmental performance of concrete structures. FIB is formed 42 national member groups and about 1000 members, both individual and corporate, in 65 countries.

***The model code***

FIB presents a model code, created in 2010. Their main intention is to develop and improve design methods and the use of improved structural methods. In order to design for structural safety, serviceability, durability, sustainability etc. certain measures need to be taken in the design stages. The aim for the conceptual design is to design and develop a structural concept (FIB, 2010).

### *Relevance for this study*

FIB is an organization that covers the design process and conceptual design for engineers. Their work were recommended by the Department of Structural Engineering at Chalmers.