12 Summary

12.1 The Systematic Approach

After examining the historical background, the fundamentals and generally applicable problem solving and evaluation methods, this book describes the product development process, starting with product planning and clarification of the task and proceeding to the conceptual and embodiment design phases. The generic solutions chapter provides stimulation for the search for solutions. To reduce development effort, approaches for developing size ranges and modular systems are introduced. The methods for quality assurance and cost estimation help increase customer satisfaction and improve market competitiveness.

Conceptual design and *embodiment design* are the two crucial phases in the creation of technical products and systems. Their respective steps are shown in Figures 12.1 and 12.2, where the various methods are correlated with their main or supporting applications (see [12.11] for an overview of methods). The figures also chart the *progress* of engineering design work and the *importance* and the *timing* of the various methods. Tasks and problems differ from product to product, and the approach and use of the methods is influenced by the branch of engineering and the characteristics of each company. This can lead to differences in the sequence of the working steps, the applications of the methods, and the uses of the terminology. The approach proposed in this book should be adapted flexibly without neglecting the underlying philosophy of the systematic approach and the various methods. In addition, not all problems or all working steps require every applicable method to be utilised.

The various methods should only be applied when they are required and useful for a particular objective. Work should never be done for the sake of systematics or for pedantic reasons alone. Depending on their inclinations, experiences and skills, designers will tend to prefer certain methods. This is particularly true when several methods are appropriate for a particular step, as it helps switch between different viewpoints and thinking levels. Switching can be achieved by large jumps forward (executing concrete steps early in the process) and subsequently returning to the original step (analysing the results and creating new ideas). When searching for solutions, switching between thinking levels plays a particularly important role. The adaptation and selection of suitable methods requires knowledge about these methods and some experience of their application. This means that methods have to be learnt and practised.

Methods (● main, ○ supporting) \ Steps		Product planning Selecting the task	Clarifying the task Setting up the requirements list	Abstracting to identify essential problems	Establishing function structures	Searching for working principles	Combining working principles	Selecting suitable combinations	Firming up into principle solutions	Evaluating principle solutions
Trend studies Market analysis	3.1	●	○							
Requirements list	5.2		●	○						
Abstraction	6.2			●	○					
Black box representation Function structure	6.3			○	●					
Literature search	3.2.1	○	○			●			○	
Analysis: natural systems	3.2.1				○	●				
Analysis: known solutions	3.2.1.		○		●	●	●		○	
Analysis: mathematical – physical relationships	3.2.1				●	●				
Tests, measurements	3.2.1					●	●		●	
Brainstorming, Gallery method, Synectics	3.2.2.	○				●				
Systematic study of physical processes	3.2.3					●				
Classification schemes	3.2.3					●	●			
Design catalogues	3.2.3					●	●			
Sketches Intuitive improvements	6.5.1					○	●		●	
Selection methods	3.3.1				○	○	●	●	○	
Evaluation methods	3.3.2									●
Quality assurance methods	10						○	○	●	●
Costing methods	11							○		●
Value analysis	1.2.3							○		○

Figure 12.1. Correlation of methods with the various steps of the conceptual design phase (numbers refer to chapters and sections)

The ability to abstract, to work systematically and to think logically and creatively complement the professional knowledge of designers. In the various design steps, these abilities are demanded to varying degrees. *Abstraction* is needed particularly for identifying essential problems, for setting up function structures,

Methods (● main, ○ supporting) / Steps		Identifying embodiment-determining requirements	Specifying spatial constraints	Identifying main function carriers	Developing preliminary layouts of main function carriers	Selecting suitable preliminary layouts	Developing preliminary layouts for the remaining main function carriers	Searching for solutions to auxiliary function carriers	Developing detailed layouts of main function carriers	Developing detailed layouts of auxiliary function carriers	Evaluating preliminary layout	Preparing definitive layout	Checking for errors and disturbing factors	Preparing preliminary parts list and production documents
Requirements list	5.2	●	●								○		○	
Function structure	6.3			●										
Solution concept	6	●	●	●	○		○							
Solution methods Generic solutions	4 8							●						
Checklist	7.2				●	○	●		●	●				
Basic rules: simplicity, clarity, safety	7.3				●	○	●	○	●	●	○	○	○	○
Principles Force transmission Divison of tasks Self-help Stability and bistability Fault-free design	7.4			●	●		●	○	○					
Guidelines Durability (Stress) Deformation Stability Resonance Expansion Creep Relaxation Corrosion Wear Ergonomics Aesthetics Standards Production Assembly Quality control Transport Operation Maintenance Recycling	7.5				○		○		●	●		●		●
Selection methods	3.3.1					●		●						
Quality assurance Risk reduction	10 7.5.12										○	●	●	
Cost identification	11					○					●			
Evaluation methods	3.3.2 7.6							○			●			

Figure 12.2. Correlation of methods with the steps of the embodiment design phase (numbers refer to chapters and sections)

for determining the characteristics of classification schemes and for applying the principles and rules of embodiment design. *Systematic and logical thinking* help in elaborating function structures, in setting up classification schemes, in analysing systems and processes, in combining elements, in identifying faults, and in evaluating solutions. *Creative ability* helps in varying function structures, in searching for solutions with the help of intuitive methods, in combining elements with the help of classification schemes or design catalogues, and in applying the basic rules, principles and guidelines. *Professional knowledge* is needed particularly for drawing up requirements lists, for searching for weak links, for selecting and evaluating, and for checking using the various checklists and fault-tracing methods.

Experience with the use of methods supports the planning and monitoring of the product development process. Domain-specific experience helps focus on and

Task clarification	Conceptual design		Embodiment design	
Setting up the requirements list	Selecting	Evaluating	Embodying	Evaluating
Determining requirements	Identifying the best combination of principles	Discovering optimum concept	Checking embodiment Determining layout, forms and materials	Identifying optimum embodiment
(Figure 5.3)	(Figure 3.27)	(Figure 6.22)	(Figure 7.3)	(Figure 7.148)
Geometry	Compatible with the overall task	Function	Function	Function, working principle
Kinematics		Working principle	Working principle	Layout desgin
Forces	Fulfils demands of the reqirements list	Embodiment	Layout	Form design
			Durability	
Energy			Deformation	
			Stability	
Material	Realisable in principle		Resonance	
			Expansion	
Signals			Corrosion	
			Wear	
Safety	Incorporates direct safety measures	Safety	Safety	Safety
Ergonomics		Ergonomics	Ergonomics	Ergonomics
Production		Production	Production	Production
Quality control		Quality control	Quality control	Quality control
Assembly	Preferred by designer's company	Assembly	Assembly	Assembly
Transport		Transport	Transport	Transport
Operation		Operation	Operation	Operation
Maintenance	Within permissible costs	Maintenance	Maintenance	Maintenance
Recycling		Recycling	Recycling	Recycling
Costs		Costs	Costs	Costs
Schedules			Schedules	Schedules

Figure 12.3. Summary of checklists with main characteristics and related working steps

speed up finding solutions, and "separate the wheat from the chaff". Frankenberger [12.5] observed in his research that experience does have a large positive effect but can also have a negative effect when that experience leads to inflexibility and fixation.

Figure 12.3 lists the *guidelines* and their main characteristics that support the creative and corrective activities in the various design phases. The lists are in accordance with the general suggestions given in Section 2.1.7, and ensure that the technical function is implemented economically and safely. To find solutions, the relationships between function structure, working structure and construction structure should be considered, as well as the general and task specific constraints. The characteristics are adapted to the level of concretisation.

Before a requirements list can be set up, the requirements must be known in detail so that the functions and important constraints can be identified. For that reason, the main characteristic "function" makes way for the associated characteristics "geometry", "kinematics", "forces", "energy", "material" and "signals", all of which facilitate the identification and description of the overall function. Similarly in the embodiment phase, the characteristic "embodiment" is replaced with the appropriate "layout" characteristics. Similar characteristics apply to evaluation; they have a welcome redundancy which ensures that they cover all contingencies. Methods of quality assurance and cost identification should be applied as early as possible, but during the embodiment phase at the very latest.

Some of the methods we have examined are applicable at different levels of embodiment and can therefore be used *repeatedly*. This is particularly the case with documentation (for example, requirements lists, function structures, selection and evaluation charts). Moreover, it has been found that systematically elaborated documents for certain product groups have a wider application in that they can be used again for other products, thus reducing the overall effort of the systematic approach.

12.2 Experiences of Applying the Systematic Approach in Practice

The overall approach and the specific methods described in this book have been applied many times to solve problems in industry. They have been applied by engineering students working on projects in industry, by faculty assisting with industrial projects, and by practising designers. The experiences gained from these activities have been analysed and published [12.1–12.3, 12.8]. With respect to the individual methods, the following conclusions can be drawn:

- Task clarification and setting up the *requirements list* prove to be essential and important methods.
- Abstracting and creating *function structures* often causes difficulties because of the abstract representation. Designers are more used to thinking in objects and visual images [12.6]. Nevertheless it is necessary and helpful that at least the main functions are identified and listed.

- *Intuitive search methods* are mainly applied when no solution seems achievable using conventional methods. For embodiment issues the gallery method is more effective than brainstorming. Both, however, can only encourage ideas. A careful analysis and further development of the results are necessary.
- *Discursive solution methods* such as classification schemes and morphological matrices initially cause some difficulties because the appropriate but abstract classifying criteria and their characteristics are not, or not fully, recognised. This suggests insufficient training in the systematic approach. However when such systematics are recognised and applied, they help to provide a more fundamental overview leading to better solutions and more patent possibilities. They also help to compare the solutions of competitors.
- *Selection and evaluation methods* are frequently used, but often, from a systematic point of view, they are combined in ways that are not recommended, resulting in individual approaches. Despite how they are often applied, selection and evaluation methods nevertheless help designers to make more objective decisions. In most cases these methods are essential.

Recent studies such as the one by Schneider [12.9] confirm the statements above. The work of Wallmeier [12.10] emphasises the importance of experience and of sustained assessment through reflection on the results to hand.

The objection is often raised that applying a systematic approach during the *conceptual design phase* takes too much time. It is true that the time needed for this phase increases for original designs. However, the time normally needed in this phase for concretising ideas into principle solutions, for example through rough calculations, developing solutions, and analyses of various layouts, is about the same as when a systematic approach is not used, that is, around 60 to 70%. Experience shows that any apparent increase in the time required is repaid several times over in the subsequent embodiment and detail design phases because irritations, sidetracks and renewed searches for solutions are avoided. Design work becomes more goal directed and efficient.

The *embodiment design phase* can also benefit directly from a systematic approach. Applying the basic rules, principles and guidelines of embodiment design usually reduces work effort, avoids errors and disturbances, and improves material utilisation and product quality. Checking solutions using the methods for identifying faults and unnecessary costs also improves the product quality, and only takes too much time when not limited to the essential. Evaluations do not take much time in comparison to the benefits, in particular searching for weak spots.

In summary:

- Industrial companies express a clear interest in systematic design especially when they are involved in original design or plan to introduce virtual product development.
- The systematic approach is being widely accepted in industry, although this may involve only the application of individual methods as the need arises.

- In particular, a systematic approach is being adopted for developing new designs where it is necessary to generate unconventional ideas, that is, to fulfil new functions with new solutions.
- The approach has hardly been introduced at all for adaptive or variant design [12.2, 12.4]. This is understandable because working with functions and function structures is not the most important task in these types of design. Adaptive and variant design benefit more from computer support.

Industrial companies applying a systematic approach state:

- The number of patents, in particular defensive patents, has increased.
- The overall duration of development projects is shorter, despite longer conceptual design phases.
- The probability of finding good solutions is greater.
- It is easier to manage the increasing complexity of problems and products.
- Creativity increases while maintaining realistic deadlines [12.7].
- A transfer effect is noticeable, that is, staff work more systematically in other areas.

The following side effects are observed:

- information flow improves
- teamwork and motivation benefit
- communication with clients increases.

A particular success of systematic design is that young engineers taught the approach and methods can contribute to a company surprisingly quickly, without first having to gain extensive experience.

The following aspects have been criticised by industry:

- Procedures for estimating costs are insufficiently developed.
- The approach can only be successfully applied when designers and managers have both been trained to use it; and both groups consistently require the other to apply it.
- Intuition and creativity cannot be replaced by a systematic approach—they can only be supported.

The overall conclusion is clear: the benefits from applying a systematic approach to design far outweigh any disadvantages.