1 *The Nature of Design*

Design Activities

People have always designed things. One of the most basic characteristics of human beings is that they make a wide range of tools and other artefacts to suit their own purposes. As those purposes change, and as people reflect on the currently available artefacts, so refinements are made to the artefacts, and sometimes completely new kinds of artefacts are conceived and made. The world is therefore full of tools, utensils, machines, buildings, furniture, clothes and many other things that human beings apparently need or want in order to make their lives better. Everything around us that is not a simple, untouched piece of nature has been designed by someone.

In traditional, craft-based societies the conception, or 'designing' of artefacts is not really separate from making them; that is to say, there is usually no prior activity of drawing or modelling before the activity of making the artefact. For example, a potter will make a pot by working directly with the clay, and without first making any sketches or drawings of the pot. In modern, industrial societies, however, the activities of designing and of making artefacts are usually quite separate. The process of making something cannot normally start before the process of designing it is complete. In some cases, for example in the electronics industry, the period of designing can take many months, whereas the average period of making each individual artefact might be measured only in hours or minutes.

Perhaps a way towards understanding this modern design activity is to begin at the end; to work backwards from the point

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where designing is finished and making can start. If making cannot start before designing is finished, then at least it is clear what the design process has to achieve. It has to provide a description of the artefact that is to be made. In this design description, almost nothing is left to the discretion of those involved in the process of making the artefact; it is specified down to the most detailed dimensions, to the kinds of surface finishes, to the materials, their colours, and so on.

In a sense, perhaps it does not matter how the designer works, so long as he or she produces that final description of the proposed artefact. When a client asks a designer for 'a design', that is what they want: the description. The focus of all design activities is that endpoint.

Communication of designs

The most essential design activity, therefore, is the production of a final description of the artefact. This has to be in a form that is understandable to those who will make the artefact. For this reason, the most widely used form of communication is the drawing. For a simple artefact, such as a door-handle, one drawing would probably be enough, but for a larger, more complicated artefact such as a whole building the number of drawings may well run into hundreds, and for the most complex artefacts, such as chemical process plants, aeroplanes or major bridges, then thousands of drawings may be necessary.

These drawings will range from rather general descriptions, such as plans, elevations and general arrangement drawings, that give an 'overview' of the artefact, to the most specific, such as sections and details, that give precise instructions on how the artefact is to be made. Because they have to communicate precise instructions, with minimal likelihood of misunderstanding, all the drawings are themselves subject to agreed rules, codes and conventions. These codes cover aspects such as how to lay out on one drawing the different views of an artefact relative to each other, how to indicate different kinds of materials and how to specify dimensions. Learning to read and to make these drawings is an important part of design education.

The drawings will often contain annotations of additional information. Dimensions are one such kind of annotation. Written instructions may also be added to the drawings, such as notes on the materials to be used (as in Figure 1.1).

Other kinds of specifications as well as drawings may also be required. For example, the designer is often required to produce

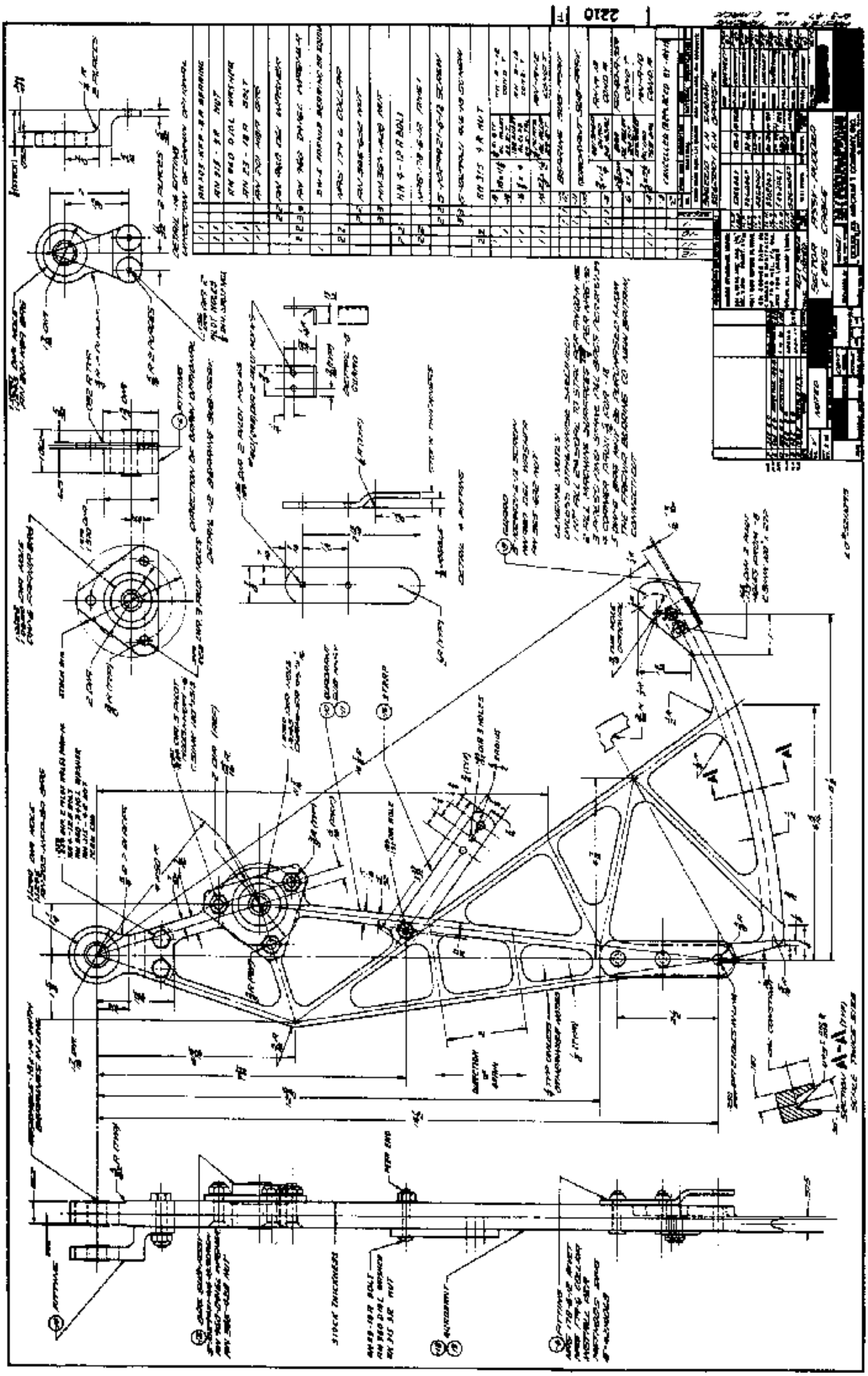

Figure 1.1 Communication: an example of a classic engineering design detail drawing

lists of all the separate components and parts that will make up the complete artefact, and an accurate count of the numbers of each component to be used. Written specifications of the standards of workmanship or quality of manufacture may also be necessary. Sometimes, an artefact is so complex, or so unusual, that the designer makes a complete, three-dimensional mock-up or prototype version in order to communicate the design.

However, there is no doubt that drawings are the most useful form of communication of the description of an artefact that has yet to be made. Drawings are very good at conveying an understanding of what the final artefact has to be like, and that understanding is essential to the person who has to make the artefact.

Nowadays it is not always a person who makes the artefact; some artefacts are made by machines that have no direct human operator. These machines might be fairly sophisticated robots, or just simpler, numerically controlled tools such as lathes or milling machines. In these cases, therefore, the final specification of a design prior to manufacture might not be in the form of drawings but in the form of a string of digits stored on a disk, or in computer software that controls the machine's actions. It is therefore possible to have a design process in which no final communication drawings are made, but the ultimate purpose of the design process remains: the communication of proposals for a new artefact.

Evaluation of designs

However, for the foreseeable future, drawings of various kinds will still be used elsewhere in the design process. Even if the final description is to be in the form of a string of digits, the designer will probably want to make drawings for other purposes.

One of the most important of these other purposes is the checking, or evaluating, of design proposals before deciding on a final version for manufacture. The whole point of having the process of design separated from the process of making is that proposals for new artefacts can be checked before they are put into production. At its simplest, the checking procedure might merely be concerned with, say, ensuring that different components will fit together in the final design; this is an attempt to foresee possible errors and to ensure that the final design is workable. More complicated checking procedures might be concerned with, say, analysing the forces in a proposed design to ensure that each component is designed to withstand the loads on it (Figure 1.2); this involves a process of

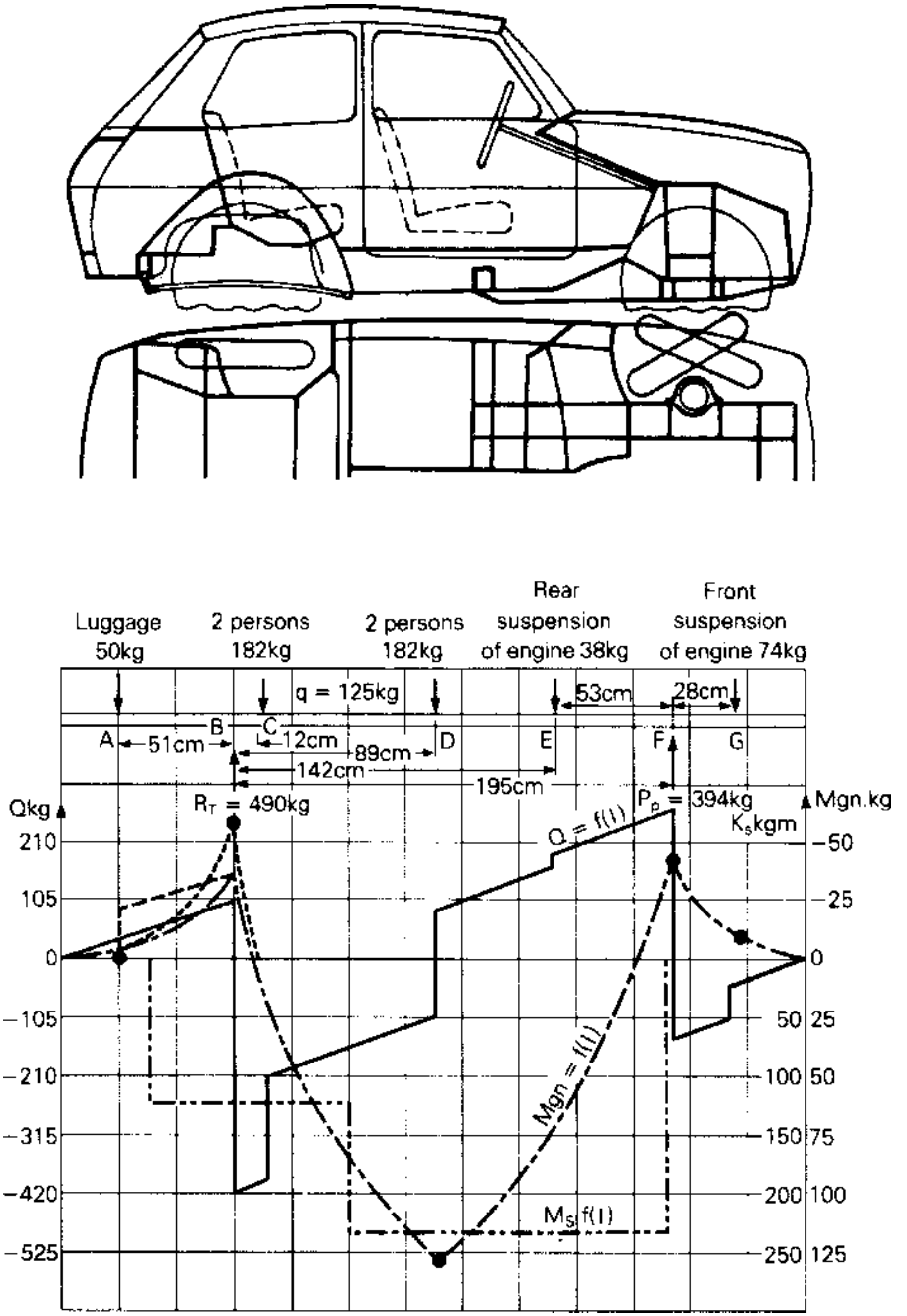

Figure 1.2 Evaluation: calculation of the shear forces and bending moments in the body of a small automobile

refining a design to meet certain criteria such as maximum strength or minimum weight or cost.

This process of refinement can be very complicated and can be the most time-consuming part of the design process. Imagine, for example, the design of a bridge. The designer must first propose the form of the bridge and the materials of which it will be made. In order to check that the bridge is going to be strong enough and stiff enough for the loads that it will carry, the designer must analyse the structure to determine the ways in which loads will be carried by it, what those loads will be in each member of the structure, what deflections will occur, and so on. After a first analysis, the designer might realize, or at least suspect, that changing the locations or angles of some members in the bridge will provide a more efficient distribution of loadings throughout the whole structure. But these changes will mean that the whole structure will have to be reanalysed and the loads recalculated.

In this kind of situation, it can be easy for the designer to become trapped in an iterative loop of decision-making, where improvements in one part of the design lead to adjustments in another part which lead to problems in yet another part. These problems may mean that the earlier 'improvement' is not feasible. This *iteration* is a common feature of designing.

Nevertheless, despite these potential frustrations, this process of refinement is a key part of designing. It consists, firstly, of analysing a proposed design, and for this the designer needs to apply a range of engineering science or other knowledge. In many cases, specialists with more expert knowledge are called in to carry out these analyses. Secondly, the results of the analysis are evaluated against the design constraints: does the design come within the cost limit, does it have enough space within it, does it meet the minimum strength requirements, does it use too much fuel?, and so on. In some cases, such constraints are set by government regulations, or by industry standards; others are set by the client or customer.

Many of the analyses are numerical calculations, and therefore again it is possible that drawings might not be necessary. However, specialists who are called in to analyse certain aspects of the design will almost certainly want a drawing, or other model of the design, before they can start work. Visualizations of the proposed design may also be important for the client and designer to evaluate aspects such as appearance, form and colour.

Generation of designs

Before any of these analyses and evaluations can be carried out the designer must, of course, first generate a design proposal. This is often regarded as the mysterious, creative part of designing; the client makes what might well be a very brief statement of requirements, and the designer responds (after a suitable period of time) with a design proposal, as if conjured from nowhere. In reality, the process is less 'magical' than it appears.

In most cases, for instance, the designer is asked to design something similar to that which he or she has designed before, and therefore there is a stock of previous design ideas on which to draw. In some cases, only minor modifications are required to a previous design.

Nevertheless, there is something mysterious about the human ability to propose a design for a new, or even just a modified, artefact. It is perhaps as mysterious as the human ability to speak a new sentence, whether it is completely new, or just a modification of one heard, read or spoken before.

This ability to design depends partly on being able to visualize something internally, in the 'mind's eye', but perhaps it depends even more on being able to make external visualizations. Once again, drawings are a key feature of the design process. At this early stage of the process, the drawings that the designer makes are not usually meant to be communications to anyone else. Essentially, they are communications with oneself, a kind of thinking aloud. As the example of the concept sketch for the 1950s Mini car shows (Figure 1.3), at this stage the designer is thinking about many aspects together, such as materials, components, structure and construction, as well as the overall form, shapes and functions.

Exploration of designs

At the start of the design process, the designer is usually faced with a very poorly defined problem; yet he or she has to come up with a well-defined solution. If one thinks of the problem as a territory, then it is largely unexplored and unmapped, and perhaps imaginary in places! As Jones (1992) has suggested, and as will be discussed in Chapter 13, it is therefore appropriate to think of the designer as an explorer, searching for the undiscovered 'treasure' of a satisfactory solution concept.

Equally, if one thinks of all potential solutions as occupying a kind of solution space, then that, too, is relatively undefined, and perhaps infinite. The designer's difficulties are therefore twofold: understanding the problem and finding a solution.

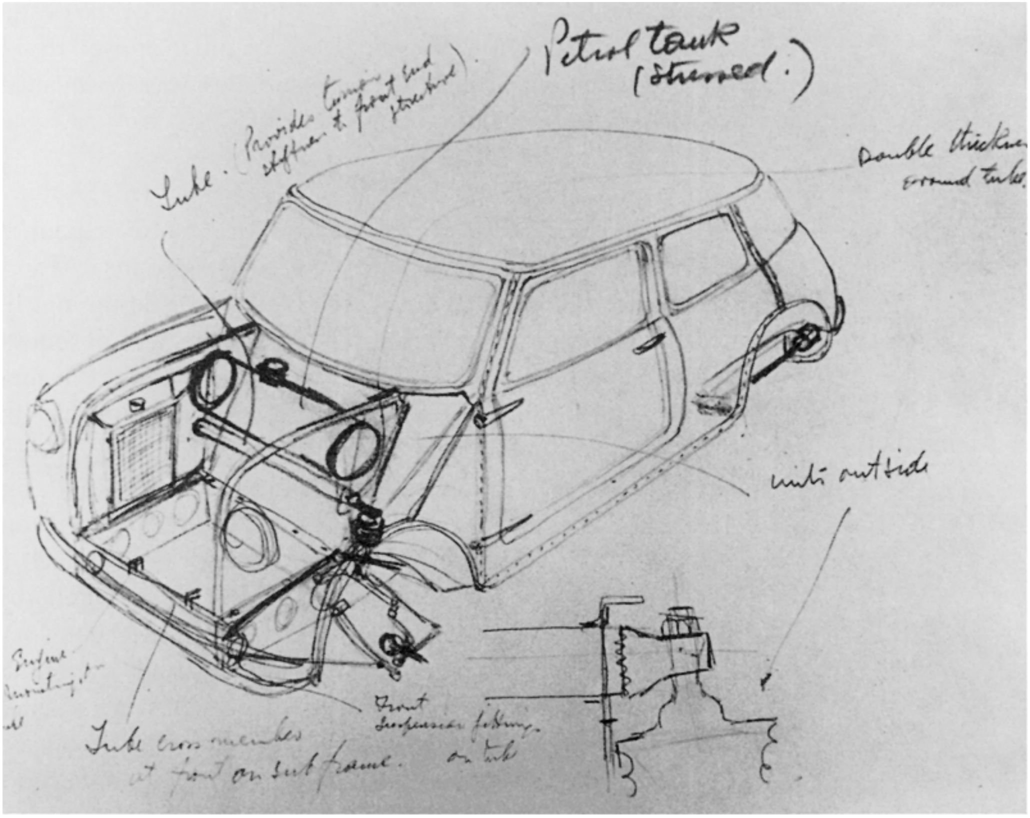

Figure 1.3 Generation: concept sketch for the Mini car by its designer Alec Issigonis

Often these two complementary aspects of design – problem and solution – have to be developed side-by-side. The designer makes a solution proposal and uses that to help understand what the problem 'really' is and what appropriate solutions might be like. The very first conceptualizations and representations of problem and solution are therefore critical to the kinds of searches and other procedures that will follow, and so to the final solution that will be designed.

The exploration of design solution-and-problem is also often done through early sketching of tentative ideas. It is necessary because normally there is no way of directly generating an 'optimum' solution from the information provided in the design brief. Quite apart from the fact that the client's brief to the designer may be rather vague, there will be a wide range of constraints and criteria to be satisfied, and probably no single objective that must be satisfied above all others, as suggested in the problem–solution 'exploration' in Figure 1.4.

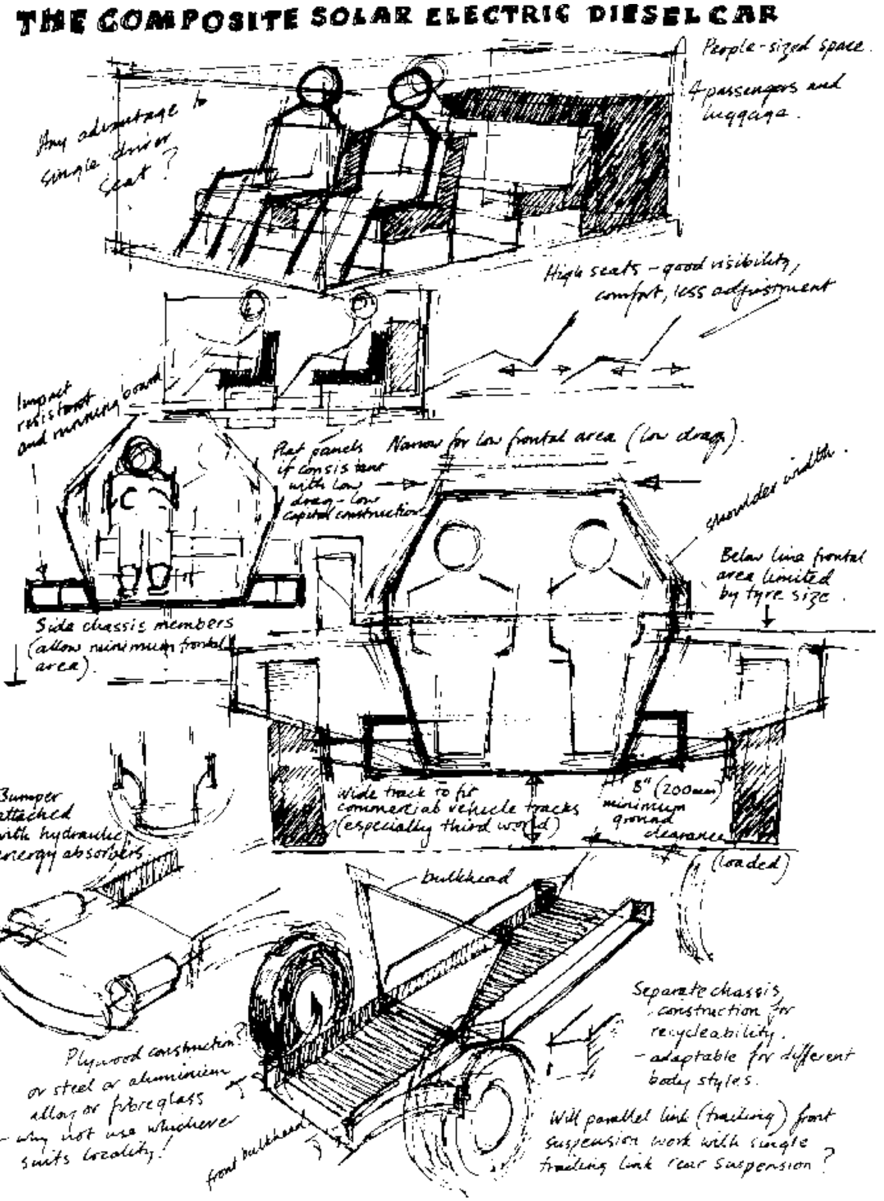

Figure 1.4 Exploration: an example of problem and solution being explored together for the Africar, a simple but robust automobile suitable for conditions in developing countries

Design Problems

Design problems normally originate as some form of problem statement provided to the designer by someone else, the client or the company management. These problem statements, normally called a design ‘brief’, can vary widely in their form and content. At one extreme, they might be something like the statement made by President Kennedy in 1961, setting a goal for the USA, ‘before the end of the decade, to land a man on the moon and bring him back safely’. In this case, the goal was fixed, but the means of achieving it were very uncertain. The only constraint in the ‘brief’ was one of time: ‘before the end of the decade’. The designers were given a completely novel problem, a fixed goal, only one constraint, and huge resources of money, materials and people. This is quite an unusual situation for designers to find themselves in!

At the other extreme is the example of the brief provided to the industrial designer Eric Taylor, for an improved pair of photographic darkroom forceps. According to Taylor, the brief originated in a casual conversation with the managing director of the photographic equipment company for which he worked, who said to him, ‘I was using these forceps last night, Eric. They kept slipping into the tray. I think we could do better than that.’ In this case, the brief implied a design modification to an existing product, the goal was rather vague – ‘that [they] don’t slip into the tray’ – and the resources available to the designer would have been very limited for such a low-cost product. Taylor’s redesign provided ridges on the handles of the forceps, to prevent them slipping against the side of the developing tray.

Somewhere between these extremes would fall the more normal kind of design brief. A typical example might be the following brief provided to the design department by the planning department of a company manufacturing plumbing fittings (source: Pahl and Beitz, 1999). It is for a domestic hot and cold water mixing tap that can be operated with one hand.

One-handed water mixing tap

Required: one-handed household water mixing tap with the following characteristics:

Throughput	10 l/min
Maximum pressure	6 bar
Normal pressure	2 bar
Hot water temperature	60 °C
Connector size	10 mm

Attention to be paid to appearance. The firm’s trademark to be prominently displayed. Finished product to be marketed in two years’ time. Manufacturing costs not to exceed DM30 each at a production rate of 3000 taps per month.

What all of these three examples of design problems have in common is that they set a *goal*, some *constraints* within which the goal must be achieved and some *criteria* by which a successful solution might be recognized. They do not specify what the solution will be, and there is no certain way of proceeding from the statement of the problem to a statement of the solution, except by 'designing'. Unlike some other kinds of problems, the person setting the problem does not know what the 'answer' is, but they will recognize it when they see it.

Even this last statement is not always true; sometimes clients do not 'recognize' the design solution when they see it. A famous example of early modern architecture was the 'Tugendhat House' in Brno, Czechoslovakia, designed in 1930 by Ludwig Mies van der Rohe. Apparently the client had approached the architect after seeing some of the rather more conventional houses that he had designed. According to Mies van der Rohe, when he showed the surprising, new design to the client, 'He wasn't very happy at first. But then we smoked some good cigars, ... and we drank some glasses of a good Rhein wine, ... and then he began to like it very much.'

So the solution that the designer generates may be something that the client 'never imagined might be possible', or perhaps even 'never realized was what they wanted'. Even a fairly precise problem statement gives no indication of what a solution *must* be. It is this uncertainty that makes designing such a challenging activity.

Ill-defined problems

The kinds of problems that designers tackle are regarded as 'ill-defined' or 'ill-structured', in contrast to well-defined or well-structured problems such as chess-playing, crossword puzzles or standard calculations. *Well-defined* problems have a clear goal, often one correct answer, and rules or known ways of proceeding that will generate an answer. The characteristics of *ill-defined* problems can be summarized as follows:

1. *There is no definitive formulation of the problem*. When the problem is initially set, the goals are usually vague, and many constraints and criteria are unknown. The problem context is often complex and messy, and poorly understood. In the course of problem-solving, temporary formulations of the problem may be fixed, but these are unstable and can change as more information becomes available.

2. *Any problem formulation may embody inconsistencies*. The problem is unlikely to be internally consistent; many conflicts and inconsistencies have to be resolved in the solution. Often, inconsistencies emerge only in the process of problem-solving.

3. *Formulations of the problem are solution-dependent*. Ways of formulating the problem are dependent upon ways of solving it; it is difficult to formulate a problem statement without implicitly or explicitly referring to a solution concept. The way the solution is conceived influences the way the problem is conceived.

4. *Proposing solutions is a means of understanding the problem*. Many assumptions about the problem and specific areas of uncertainty can be exposed only by proposing solution concepts. Many constraints and criteria emerge as a result of evaluating solution proposals.

5. *There is no definitive solution to the problem*. Different solutions can be equally valid responses to the initial problem. There is no objective true-or-false evaluation of a solution; but solutions are assessed as good or bad, appropriate or inappropriate.

Design problems are widely recognized as being ill-defined problems. It is usually possible to take some steps towards improving the initial definition of the problem, by questioning the client, collecting data, carrying out research, etc. There are also some rational procedures and techniques which can be applied in helping to solve ill-defined problems. But the designer's traditional approach, as suggested in some of the statements about ill-defined problems listed above, is to try to move fairly quickly to a potential solution, or set of potential solutions, and to use that as a means of further defining and understanding the problem.

Problem Structures

However, even when the designer has progressed well into the definition of a solution, difficulties in the problem structure may well still come to light. In particular, subsolutions can be found to be interconnected with each other in ways that form a 'pernicious', circular structure to the problem – e.g. a subsolution that resolves a particular subproblem may create irreconcilable conflicts with other subproblems.

An example of this pernicious problem structure was found in a study of housing design. The architects identified five decision areas, or subproblems, concerned with the directions of span of the roof and first floor joists, and the provision of load-bearing or nonload-bearing walls and partitions at ground- and first-floor levels. Making a decision in one area (say, direction of roof span) had implications for the first-floor partitions, and therefore the ground-floor partitions, which had implications for the direction of span of first-floor joists, and therefore for which of the external walls would have to be designed to be load-bearing. This not only had implications for the design of the external wall elevations, but also for the direction of span of the roof; and so one comes full circle back to the first decision area. This problem structure is shown diagrammatically in Figure 1.5, illustrating the circular structure that is often found in design problems.

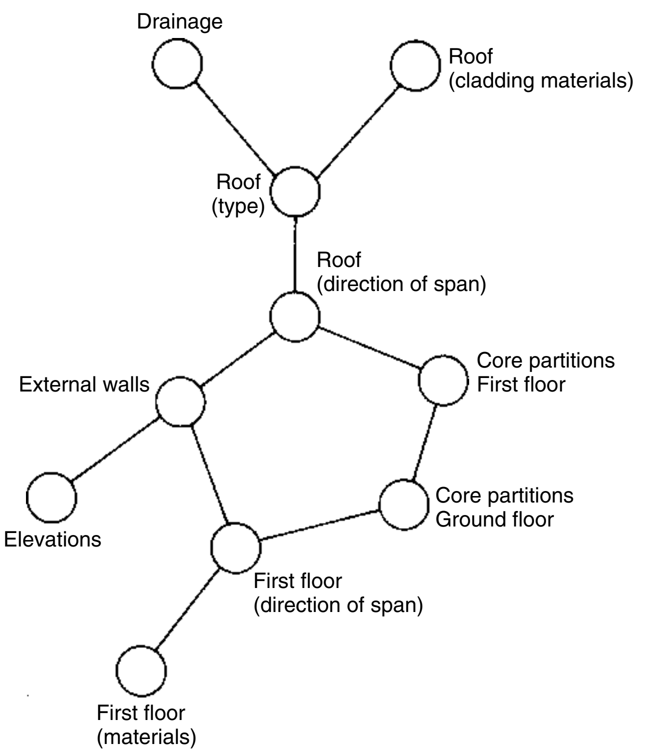

Figure 1.5
Problem structure found in a housing design problem

As part of the research study, the individual subsolution options in each decision area were separated out and the incompatible pairs of options identified. With this approach, it was possible to enumerate all the feasible solutions (i.e. sets of five options containing no incompatible pairs). There were found to be eight feasible solutions, and relative costings of each could indicate which would be the cheapest solution. This approach was later generalized into a new design method: AIDA, the Analysis of Interconnected Decision Areas (Luckman, 1984).

This example shows that a rigorous approach can sometimes be applied even when the problem appears to be ill-defined and the problem structure pernicious. This lends some support to those who argue that design problems are not always as ill-defined or ill-structured as they might appear to be. However, research into the behaviour of designers has shown that they will often treat a given problem *as though* it is ill-structured, even when it is presented as a well-structured problem, in order that they can create something innovative.

Research has also shown that designers often attempt to avoid cycling around the pernicious decision loops of design problems by making high-level strategic decisions about solution options. Having identified a number of options, the designer selects what appears to be the best one for investigation at a more detailed level; again, several options are usually evident, and again a choice is made. This results in what is known as a 'decision tree', with more and more branches opening from each decision point. An example is shown in Figure 1.6, based on a study of an engineer designing a 'carrying/fastening device' for attaching a backpack to a mountain bicycle.

This decision tree was derived from an experimental study in which the designer's progress was recorded over a two-hour period. The decision tree shows how higher-level strategic decisions (such as, in this case, positioning the device at either the front or rear wheel of the bicycle) gradually unfolded into lower-level implications and decisions, right down to details of screws, pins, etc. (Dwarakanath and Blessing, 1996).

The decision tree analysis of the design process perhaps implies that the result is the best possible design, if the best options are chosen at each level. However, a decision at any particular level may well turn out to be suboptimal in the light of subsequent options available at the other levels. For this reason, there is frequent backtracking up and down the levels of hierarchy in the design tree.

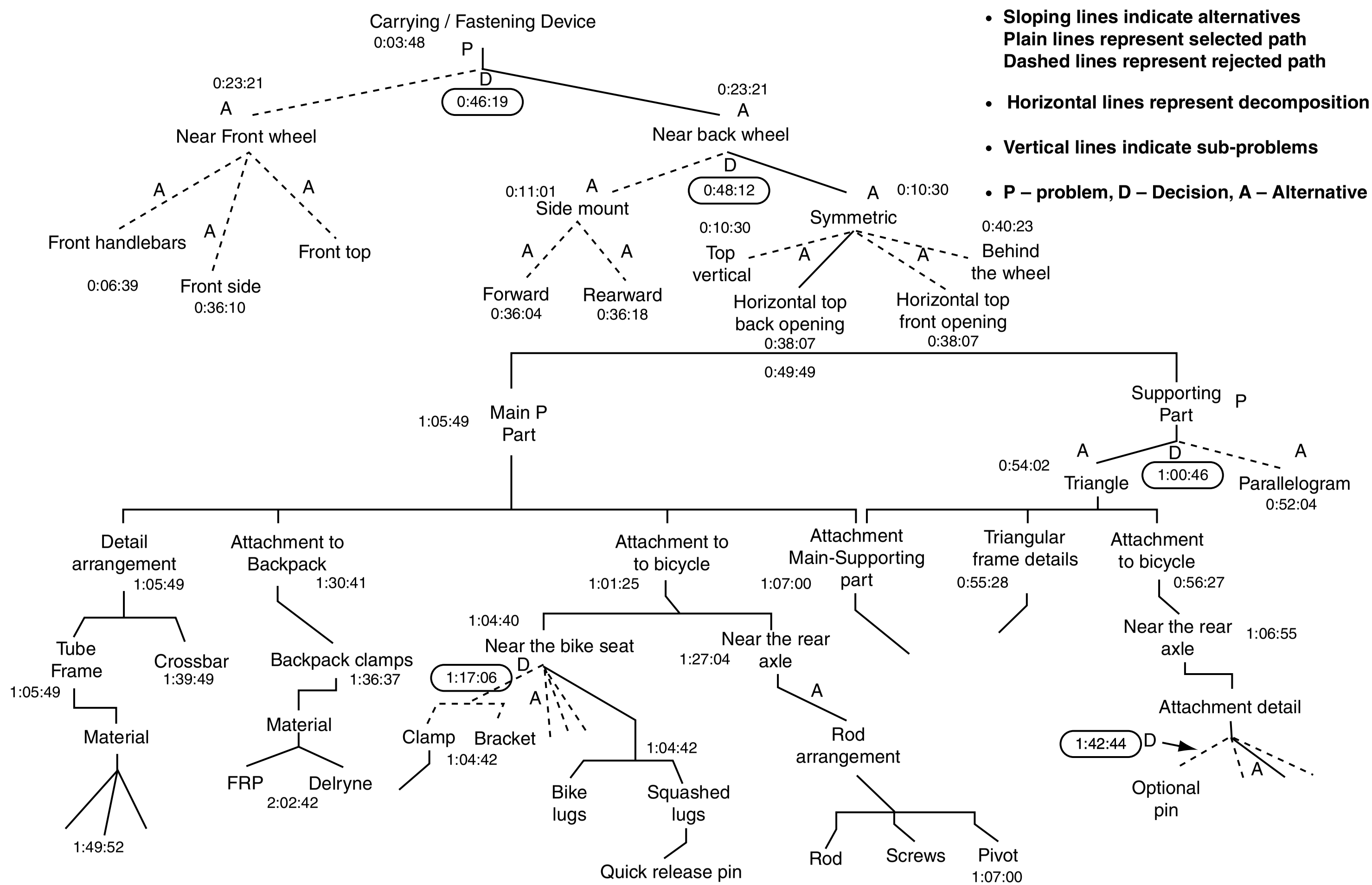

Figure 1.6 Decision tree derived from the design of a device for carrying a backpack on a bicycle

In Figure 1.6 this is confirmed by some of the 'time stamps' inserted at points within the tree, recording the time at which the designer considered the various alternatives and made decisions.

Resolving design problems by a 'top-down' approach is quite common, although sometimes a 'bottom-up' approach is used, starting with the lowest-level details and building up to a complete overall solution concept.