Ockham's Razor
and
The Changing Nature of Engineering
(Prepared for ABC 1997)

Engineering is, and has always been, about developing and applying technology to meet peoples' needs and to improve the quality of their lives. And indeed, when you look around you, there are not many objects that have not had engineers involved in their development, design, or manufacture. So, what do I mean by "The Changing Nature of Engineering"? How is engineering changing? What is it that is changing? Summed up in a single sentence, what is changing is the complexity of what engineers do; the complexity of engineering projects is increasing almost from day to day. This is in part reflected in the increased complexity of the technology used and in the size of the projects, but above all it shows up as a whole new dimension which relates to the user perspective and, in the broadest context, to community concerns and values. For example, if the engineering of a new high-voltage transmission line takes six months, the interaction which has to take place with the community before the line can be built may take several years. The image of engineers as "back-room boffins" that work in splendid isolation and come up with brilliant new technology is rapidly becoming irrelevant; what people want are cost-effective solutions to their specific problems, and this is only possible if engineers interact closely with everyone affected by their products. It is this interaction with the users and the community at large which makes engineering so much more complex today; after all, the behaviour of human beings is orders of magnitude more complex than the laws of physics.

If you accept that the complexity of engineering is increasing, you might wonder what is driving this change? Well, there are at least two valid answers to this. Firstly, we are becoming much more aware of the fact that our resources are limited, we are all "feeding from the same trough", so to speak, and this competition for scarce resources results in a much closer scrutiny of the overall benefits of engineered products and much greater pressure on their costs. Secondly, the technology-explosion and "can do" attitude following the Second World War has in a way led to more technology than we know what to do with; the question today is not so much "can it be done?" as "should it be done?". - A third answer, which is closely related to the first, is that, due to economic pressure on engineered products, the designs are much closer to the edge than they used to be, the margins of safety are reduced. This, coupled with the large number of engineered products in our everyday lives, involves engineers increasingly in the complex issues of safety and community perceptions relating to the value and quality of human life.

Having now seen what is changing and why, we can look briefly at how engineering is responding to this challenge; how engineers are changing their approach to handling complex problems. The new approach involves bringing together two distinct ideas; the first one related to how the mind works, the second one arising from the fact that we can describe an object in two quite different ways.

Let us start out by recognising that "complexity" is a relative concept. What is complex for a computer can be very simple for a human, and the other way around. For example, taking the square root of large numbers is complex for us but easy for a computer, whereas recognising a person on a photograph is easy for us but very difficult for a computer. So, when we speak of complexity in engineering, it must be understood to be relative to how the mind works, because engineering problems are solved in the minds of engineers, and to explore this, consider for a moment the house or building in which you live, or any other building which you see every day. If I ask you to describe it to me, you will start out which such general features as size, colour, number of stories, type of material, etc., but soon you run out of detail. How far do the eaves stick out? How many downpipes are there from the gutters? Is that one window in the centre of the wall or off-set? Even though this information is available to your mind each time you look at the house, your mind handles such a complex object as a house by stripping away most of the detail, what you remember is an image or representation of your house characterised by just a small number of parameters.

Modern engineering does the same; it starts the design of a complex object by first creating a simplified image or model of the object; a model which is characterised by only a few main parameters, for example cost and size, and that model is used to determine a first set of values for these main parameters. In a second step, this first model is split into a small number of models, each one the simplified image of a part of the complex object we are trying to design, and again we determine values for the parameters of these models on this more detailed level. We continue this step-wise process until we reach a level of detail where all the models on that level together are no longer a simplified image, but an exact representation of the object. We have then completed the design and determined the values of all the parameters describing the complex object while working only with relatively simple models. Because this design method proceeds from the general to the detailed, it is called a top-down approach.

The second idea arises from realising that there are two completely different ways of describing an object; either by what it *is* or by what it *does*. To illustrate this, consider such an every-day object as a coat hanger. You can describe a particular coat hanger by giving all its dimensions, specifying the material it is made of, describing the surface finish, and so on. On the other hand, you could describe what a coat hanger is supposed to do; what type and range of garments must be able to be suspended from it, what it must be able to be suspended from (i.e. a hook or a bar), that is must not crease the garments, etc. What you are describing is the coat hanger's purpose or functionality, and this general idea or image of what a coat hanger does is called a *functional element*. To a particular functional element, such as the general idea of a coat hanger, there corresponds a vast number of physical realisations, using different shapes, materials, colours, etc., and therefore you could say that the functional element is at a higher level than the physical objects which correspond to it.

While these two ideas - simplification through initially hiding detail and then revealing it in a step-wise process, and representing classes of physical objects as functional elements - are distinct, they are both concerned with reducing complexity, and when the first idea is applied to the purpose of the object to be designed, that is, to its functionality, a very significant reduction in complexity is achieved.. To understand why this is a significant change and how it operates in practice, we need to compare it to the traditional design methodology. How would you go about designing something you want to construct, such as a cupboard or a shed? Well, you would probably start out by considering the materials and construction elements known to you and reasonably available to you, such as standard timber sizes, fasteners, hinges, etc., and then you would start to combine these in your mind and on paper, trying out various combinations until you find one which suits all your requirements. That is, your design activity takes place completely in terms of physical objects, in what we called the physical domain, and your focus is on the technology available to you. And this is essentially how engineers have traditionally gone about design. They start out with the technology available to them, in the form of basic physical components, such as resistors, capacitors, shafts, bearings, beams, columns, etc., as they have been taught in their first years at university, and then they combine these components to create the object which should display the desired functionality. If it does not, they change the combination one or more times in a cut-and-try process until it gives the right performance. The problem that arises with this approach is that if the object they are trying to design is very complex, then it is likely that a large number of steps are needed, so that the design process becomes very inefficient. Because this process starts out with all the basic components and ends up with the single, finished object, it is called a bottom-up approach.

In order to overcome the inefficiency problem, the new methodology precedes this bottom-up process with a top-down process using functional elements. Starting out with the most general description of the functionality as a single functional element, this is refined, as we described a moment ago, in a step-wise process which describes the functionality in terms of more and more, smaller and smaller functional elements, until the complexity of the individual functional elements has been reduced to a point where their physical realisations can be designed efficiently using the traditional method. And, as you can see, the top-down process is not technology-driven, but requirements-driven; at the top of the design process stand the users' requirements, acting as a guiding beacon throughout the whole process. Technology is only brought in towards the end of the design process as a means of providing the functionality which satisfies those user requirements. So, the new approach allows us to cope more efficiently with complex design problems, and it shifts the emphasis of the design process from finding applications for technology to meeting the users' requirements.

Well, this has been a very brief overview of what is a reasonably complex subject, but hopefully you have gained an impression of how engineering is currently changing to meet the increasingly complex demands of society. The focus of engineering is swinging away from being purely on technology, towards a greater involvement in the business side of technology-based enterprises and in the concerns of the people affected by the engineered products.