An Engineer Imagines

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The Role of the Engineer

I am an engineer. Often people will call me an 'architect engineer' as a compliment. It is meant to signify a quality of engineer who is more imaginative and design-orientated than a normal engineer. This is because in the minds of the public and of other professionals, the engineer is associated with unimaginative dull solutions. If people find an engineer making original designs, designs which only an engineer can make, they feel the need to grant him or her a higher accolade, hence 'architect engineer'. It is not that I object to being called an architect engineer. Occasionally it may even be appropriate, but mostly it is not because there is a fundamental difference between the work and way of working of an engineer and that of the architect or designer.

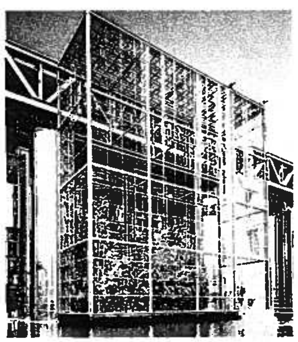
To call an engineer an 'architect engineer' because he comes up with unusual or original solutions is essentially to misunderstand the role of the engineer in society. It is easiest to explain the difference between the engineer and others by comparing how each works and what they do. Designers such as the famous car stylists, like Pininfarina, or Giugiaro, work essentially from within themselves. They respond to a design challenge by seeking to understand how they respond to the context and the essential elements of the problem: their response is essentially subjective. Different architects will respond very differently to the same problem. Their solutions will reflect their style preference and their general belief in an appropriate response to a problem. Thus, if you ask a particular architect to respond to a design challenge, he will always give a solution based on the classical order, a solution which reflects his belief that the classical order is the only satisfactory response which preserves an urban sense of scale and recognizes a link with the past which he interprets in this way. Other architects would choose a different approach based on their subjective reactions as to what an appropriate architectural response should be. Both the likely responses would be known beforehand and would probably have been an important factor in the selection of the architect in the first place. An architect's or designer's response to any design challenge is subjective and is based on his feeling on the correct and appropriate response. He is employed to express his personal view of the correct solution.

1960 Ferrari Coupe 250/GT designed by Pininfarina.

An engineer and an architect would rarely find themselves tackling the same kind of problem, but it does happen, as I will demonstrate later in this story. The engineer when faced with a design

Lloyd's of London, detail of concrete bracket.

Lloyd's of London, view of concrete structure in atrium.



View of a Grande Serre at the Musée des Sciences et de l'Industrie at Parc La Villette, Paris.

challenge will transform it into one which can be tackled objectively. As an example, the engineer might seek to change the problem into the exploration of how to exploit a particular material completely within the context of the architecture.

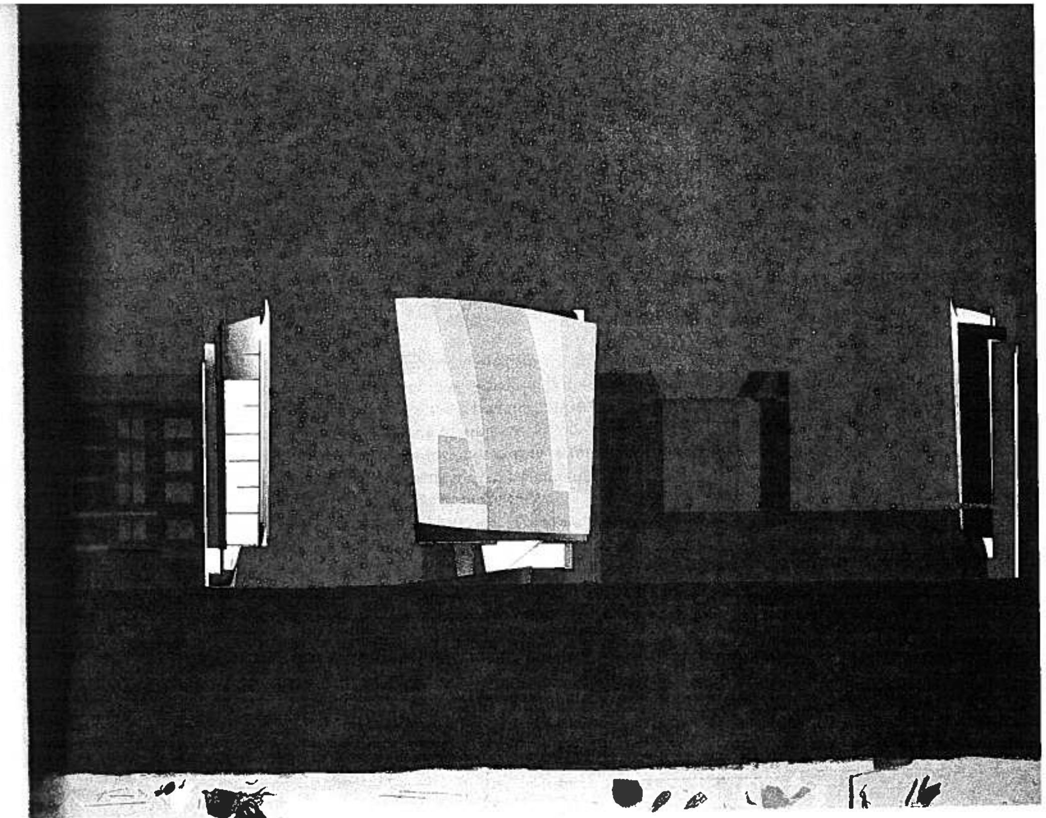
Thus the Lloyd's of London building became an exploration of the use and properties of concrete. And the engineer's contribution was to try and make the structure an essay on expression in the use of concrete. But it was the properties of concrete which motivated the search and the solution.

Similarly at the La Villette 'greenhouses' in Paris. The architect defined the architectural intention, and the engineer transformed the simple architectural statement into an essay on the nature of transparency and of how to use the physical properties of glass to convey fully the concept of *transparence*. As an engineer I worked essentially with the glass. It was the properties of the material which motivated the development of the design. Thus, although we can say that there was originality and aesthetic choice in the way that the design developed, this way forward was directed by the need to express the properties of the glass in full.

I would distinguish the difference between the engineer and the architect by saying the architect's response is primarily creative, whereas the engineer's is essentially 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. Indeed, now it is important that engineers start to educate both people within the profession and the public at large on the essential contribution that the engineer makes to even the most mundane project. To begin that process, and to understand fully the problems we engineers face, I would now like to examine the situation of the engineer in general.

Engineers to many people, especially to the public, are mysterious figures. The most frequent remark is: 'What do they do? They just makes things stand up,' as though this were not a noble thing to do. No, in our media-dominated society it is the image not the content which matters. But the engineer's role is crucial nonethe-



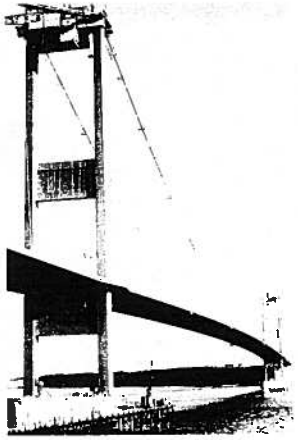
Kurfürstendamm 700, Berlin
The design of the smooth, gently curving and tilting skin is based on an adaptation of a conventional structural curtain wall, where the grid is a structural mesh of aluminium extrusions suspended from the top floor in a continuous sheet. The sliding connections to lower floors must restrain wind loads lateral to the glass but not vertical loads.

less, even in matters of image. The problem is that, in the simple world that the media favours, the role of image-making is given to others – to designers, for industrial artefacts such as cars, household goods, and so on; and to architects for the monuments of our built environment. It is not that there is anything wrong with this approach *per se*, it just ignores the vital role played by engineers in the creation of all the things that are built or made today.

'Engineer' is not a proud word in our language. It is not a word to make you stand up and beat your chest. Sometimes it is associated with electricians or other craftsmen from unionized labour. This distortion at the bottom end of the scale is the prevalent thought in the mind of many in Great Britain, although this is less so in France, Italy, Spain, or Germany. The engineer is not identified with other professions, such as lawyer, doctor, architect. The word 'engineer' offers no protection. Anyone can say he is an engineer – not a chartered engineer, but the distinction is fine, and hardly one that the general public could be expected to understand. And even those who do understand have difficulty in understanding what the engineer actually does. How then does this come about?

Partly it may be explained historically. But the provenance of the engineer in the nineteenth century is noble indeed. Telford, Stephenson, Brunel father and son, Eiffel, these are names of pride and achievement, names that any profession would welcome as their antecedents. Indeed in their time they outshone architects and other designers and their achievements are still spoken of with awe.

Where have we gone wrong? Are we somehow different today, doing less exciting, less urgent, less vital tasks in our complex modern world? But then we have sent men to the moon. Grey people, you say, working in teams, not great individuals placing their personal authority on the line in what they design. But is that true? Of course not. Every team has a leader, one who is ultimately responsible for the work that the team does. Remember the O-rings on the Challenger space shuttle, or the engineer responsible for the DC10 which crashed near Orly in 1974. There it was clear what the engineer's role was. The problem, then and today, is that the name and role of the engineer are not known to the public. Engineers work incognito. Unlike their predecessors, today's engineers work behind a screen of other egos. The great nineteenth-century engineers were of course entrepreneurs as well as engineers, financing and being financially responsible for the artefacts they constructed.

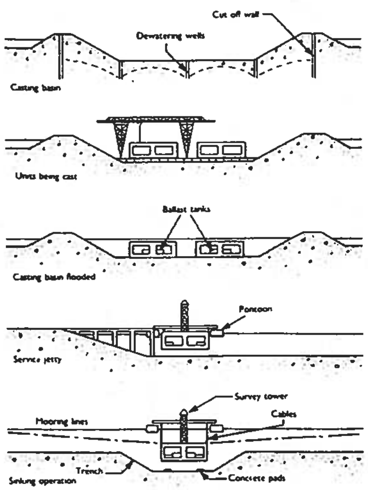


The Severn Bridge.

Engineers then, as engineers now, were doing the same job and taking the same responsibility.

The engineer's role in the design of large structures is easy to understand. Take the bridge which carries the M4 motorway across the River Severn. That bridge in its time was highly innovative. It was much lighter than other bridges being built at that time, such as the Verrazano Narrows Bridge in the USA, and it spawned a completely new way of making very long suspension bridges. The Humber and Bosphoros bridges are two bridges made by the methods pioneered in the Severn Bridge. The invention and innovation shown in these designs came from the engineers Freeman Fox of London. Another example of recent inventive engineering, not so visible but as original, is the Conway crossing in north Wales. Here the engineers made two concrete tubes, in precast elements, joined together on the surface, which were sunk into two trenches pre-dug on the estuary floor. By evacuating the water from the preformed tubes an underwater road tunnel was created.

The Conway Crossing, construction sequence. Concrete tunnel tubes are cast, floated to site position and sunk. The water is then evacuated.



I include these two recent examples of the work of engineers to show that today's engineers are just as daring, just as inventive as their Victorian counterparts. It's just that even when we know about their work, we don't have a label to attach to the work.

I believe that it is this lack of a personality to identify with the work which is the fundamental weakness of the engineer's position. Engineers need identity. Engineers need to be known as individuals responsible for the artefacts they have designed.

But what is also needed is to communicate some of the excitement of engineering. The truism of engineering is to say that engineers have, as their challenge, the conquering of the great and varied forces of nature. And that is of course true. Gravity, wind, snow, earthquake are all parts of the challenge. The essence of the engineer's role as a designer is to conceive works to withstand whatever forces the natural environment and people place upon them. Other engineers – water engineers, environmental engineers, foundation engineers – all have great primeval forces to withstand in their designs. Assessing these forces and being sure that they have been properly accounted for is far from automatic. Codes and tradition give a guide but they are just the beginning. They do not cover specific situations, and therefore the engineer is always left to make the final assessment.

Engineering is challenging and exciting and requires the highest skill. And it is glamorous. It is just that we fail as engineers to explain what we do and how we do it. It is important in all this that we recognize and explain that there are many decisions that only an engineer can make.

The gerberette at Beaubourg is an example of an apparently architectural decision that could only have been made by an engineer. It is this special role of the engineer which needs to be better understood. We have first to understand how this role differs from that of the architect. Broadly, the architect responds to the site, the context of the situation, and creates an emotional response to the situation. It is his personal assessment.

The essence of the engineers' problem then is that their work is either not understood or is given scant treatment by the media; even the engineers' own media fail fully to express the mystical excitement of the engineering challenge.

However, within the context of the work which engineers do themselves, there are certain features which make the role of the engineer sharper. An engineer must not be wrong, because human life and human safety are dependent on the engineer's work being right. That is the bottom line.

In this general world the engineer's work is not understood and is not valued for the contribution it makes to even the most mundane of artefacts. I want to show, principally through the work I have done as an engineer, the scope for inventiveness and innovation that exists, and also to identify how the engineer's contribution can enhance the architecture of many artefacts.

Of course I do not wish to imply that all engineers are somehow unappreciated geniuses waiting for the opportunity to express their inventive skills. This is clearly not the case. The argument is that there are many engineering contributions which go unrecognized, or which are attributed to the architects or others with whom the engineer is working.

Many engineers are themselves affected by the general expectation that society places upon them and they behave accordingly. Indeed they may in their pragmatic way encourage and foster the very atmosphere that inhibits them when they wish to be inventive. This I call the 'Iago mentality'.

There is an essay entitled 'The Joker in the Pack' in W H Auden's collection *The Dyer's Hand*. In it he examines the role of Iago and his unfailing rational arguments in the destruction of romanticism.

Iago (David Suchet) reasons with Othello (Ben Kingsley), Royal Shakespeare Company production (1985).

In *Othello*, Iago uses sound, sensible arguments throughout to destroy the romantic idyll of Othello's existence.

Iago, as the agent of rational argument, undermines those fragile characteristics of love and loyalty by the constant application of simple rational argument. Science, Auden argues, also destroys our romantic and artistic creativity by constantly requiring us to pass the test of rational acceptance. In the dialogue of architecture and engineering, the engineer is the voice of rationality and reason. It is a role which is all too easy to play. After all, one is being sensible, reasonable, modern in questioning the more far-fetched flights of fancy of some architectural proposition. This then is the engineer's principal destructive weakness, to play Iago to the architect, or indeed to another engineer, Othello. In Alexander Pope's phrase, what the engineer can do is to 'Damn with faint praise …' and in so doing destroy the fragile shoots of creativity in others. It is of course not only engineers who can be part of the destructive process. Richard Weinstein, who first introduced me to Auden's essays, held as his thesis that much of the modern architectural development which relies upon scientific correctness to justify its decisions is in the grip of the Iago approach. Such a position obscures the individual contribution of the architect and buries it in apparently rational justification. And although this is not the work of the engineers, it uses adherence to engineering principles to justify its choices.

Is there any escape for the engineer in this world of rational absolutes? I believe that there is. Let us examine again the role that engineers play, or at least can play. They work with materials. They can work with light. They can work with air. They work with the basic and fundamental elements of construction. They work with the content, not the image. It is a truism that most people find modern architecture cold and alien. Whereas a Gothic cathedral will express the real and physical presence of the stone from which it was made, and of the masons who laboured over its construction so many years ago, very few modern buildings carry the same physical presence of the materials of which they were built. In short, the *traces de la main*, the evidence of those who built it, is not there. These buildings are not tactile.

This is the positive role for the engineers' genius and skill: to use their understanding of materials and structure to make real the presence of the materials in use in the building, so that people warm to them, want to touch them, feel a sense of the material itself and of

the people who made and designed it. To do this we have to avoid the worst excesses of the industrial hegemony. To maintain the feeling that it was the designer, and not industry and its available options, that decided, is one essential ingredient of seeking a tactile, *traces de la main* solution.

A building does not have to be made of brick or stone to achieve this, but rather it is the honesty and immediacy in the use of its principal materials which determines its tactile quality. That was the essential reason for the use of cast steel in Beaubourg, and for many other choices which will be explained elsewhere.

This then is a noble role that the engineer can assume – the role of controlling and taming industry. The building industry has an enormous investment in the *status quo* and, like Iago, will use every argument to demonstrate that other choices are irrational and not very sensible. Only the engineer can withstand these arguments, demonstrate the wrongness of the position of industry and demolish its arguments. In this scenario, the engineer becomes critical and can save his soul.

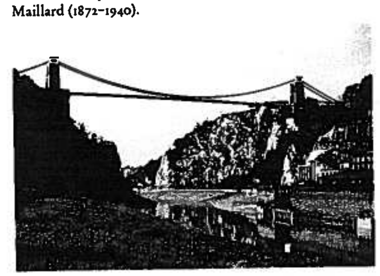
In general, though, the most powerful way that an engineer can contribute to the work of architects is by exploring the nature of the materials and using that knowledge to produce a special quality in the way materials are used.

Exploration and innovation are the keys. I have noticed over the years that the most effective use of materials is often achieved when they are being explored and used for the first time. The designer does not feel inhibited by precedent. For example, there is little to compare with the expression of the nature and character of concrete form in the bridges of Maillart. He made forms and shapes which fully reflect the way concrete is made and the plastic forms that can be achieved with it. Maillart's concrete compares with Brunel's use of steel or Telford's use of iron.

In any of these structures there is a simple honesty which goes straight to the heart of the physical characteristics of the material and expresses them in an uninhibited way. This implies – and I believe it to be true – that when we can re-create as engineers that sense of adventure and innovation, we will be most successful in giving the tactile quality to our designs.

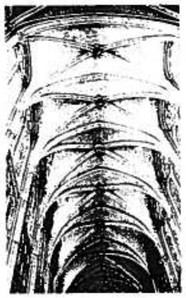
A design does not just have to be something you can touch; it can be tactile when a material is used to express its inner nature with feeling and is clearly the work of a designer who, in thinking about

1930, Salginatobel Bridge, Switzerland by Robert Maillard (1872–1940).



1864, Clifton Suspension Bridge by Isambard Kingdom Brunel (1806–1859).

1826, bridge over the Menai Straits by Thomas Telford (1757–1834).

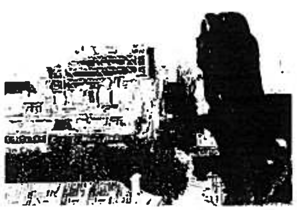


Vaulted ceiling of Chartres Cathedral.

the material, has made the perception of the material more real. Thus I believe that the glass walls at La Villette are tactile even though it is not possible physically to touch them.

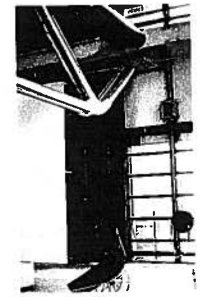
Throughout this book I use the word 'tactile'. What do I mean by talking of architecture being tactile? Tactile quality is like empathy. It is like the feeling you get when you visit a particularly hallowed place. A friend recently described to me the powerful presence she felt when visiting Jerusalem, and especially when visiting the great religious places of the city. Generations of people have made their presence felt and left visible and invisible evidence of their presence. Gothic cathedrals, and many Renaissance palaces and churches, have this quality. This is helped of course by the fact that these were built of natural materials. But it is something more than that, some presence which puts you in contact with the building and the past. Animals too have this need to reassure themselves of others who passed before them when they go exploring or checking out a new place. They seek the scent of previous occupants. For that reason I believe that the primary quality which makes the built environment tactile is evidence that people have participated in its construction. It is for that reason, when I think of the alienation which exists today between people and the built environment, that I put it down primarily to the all-pervasive and essentially sterile role of industry, which suggests that decisions about this environment were made not by people but by the needs of industry.

The search for the authentic character of a material is at the heart of any approach to engineering design. This statement may seem excessive and even frivolous to many engineers. And it is important to emphasize that one should not invent and innovate just for its own sake. Innovation should have a real purpose and be contributing to the project. Nevertheless, some extra design element should be every engineer's objective whatever the project he is working on.



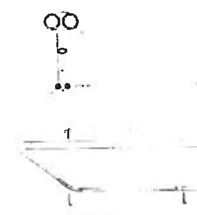
Stone gargoyles of Notre Dame Cathedral, Paris.

What about the engineer's basic obligation to build as cheaply and as economically as possible? I do not believe that economy and innovation are necessarily incompatible. Any project has cost constraints which must be met. They are a fundamental part of the design challenge, and finding a way to add one's special extra quality while respecting all the other parameters is one of the things which can make the challenge of design interesting and exciting to the engineer.



A double boom beam, Pompidou Centre, Paris.

Finally I would like to discuss the relationship of the engineer and the design concept. One day I was discussing with the architect Richard Rogers the fact that many of my contributions to design seem to arise as a complete concept. By this I mean the solution to the problem will often come fully worked out. I give two examples. The main beam in Beaubourg, with its double top chord and double bottom chord and the cast nodes which connect the double booms to the single-layer sheer members, appeared fully formed in my mind one night in bed. I guess that concentration on the search for a solution over the previous weeks had defined the problem very clearly. Nevertheless this complete beam form was there when I awoke, and it did not change in any important aspect during the subsequent architectural development. It even had what became one of the basic design rules for the Beaubourg steelwork built into the solution. This was the use of solid rounds for tension, tubes in compression members and castings for the node. How did this happen? I am not too sure. What I do know is that the decision to use double booms came from the belief that some light passing between the booms would lighten their visual impact very considerably, and that lightness was of vital importance in a beam which was spanning 45 metres and penetrating into the space.



Sections and elevation of a double boom beam, Pompidou Centre, Paris.

The complete structural solution for the floor of the Lloyd's of London building came to my mind one evening in Turin while I was working on the Fiat project. The grid and the relationship between the columns and the floor beam grid were all there in the concept from the beginning. We had been discussing the problem very thoroughly during the previous weeks, so it is not surprising that I should have been thinking of a possible solution. But that the solution should arise fully formed is, I think, unusual. It is characteristic of the way engineers think: because they are working with objective parameters these lead to only one conclusion.

When I discussed this proposition with Richard Rogers he averred that it had always been true of the work of engineers. The bridges of Telford and Brunel, he felt, had probably arisen in their final form from the beginning and the engineers only needed to prove that they worked rather than modify and change them to get them exactly right. I think this is how I work. Once a solution appears to solve the problem, then I don't feel any desire or compulsion to change it. If it's a solution it is a solution and so be it.

I think this characteristic of working in concepts is quite common for engineers. It arises with architects too sometimes, but it is probably a fundamental aspect of all engineering designs.

Invention, innovation and creativity are three of the great buzz words of today. To be creative or innovative, especially, implies a God-given talent, possessed by the few for the rest of us to admire. From the outside it seems impossible to achieve these qualities, as though somehow the gifted appear to have some mystical status, a status that cannot be claimed, only conferred.

How can we become innovative or creative? As I have argued already, the creative talent is essentially artistic and is essentially associated with architects, designers or artists. For the engineers or other practitioners in science or fact-based information, the aim is to innovate. Is this so different? I think not.

It is a myth that there is something special about the innovative engineer. Probably every solution put forward by an engineer has some unusual element, some feature that could be called innovative, but is not recognized because it is buried in an otherwise conventional solution. And if we examine the nature of these otherwise innovative or inventive elements, we will find that it is just the result of the engineer being intelligent or sensible about the way some detail has always been, and so reassessing the problem from another point of view.

This kind of innovation arises a hundred times a day on building sites throughout the world. It is taken for granted. But it is nonetheless an important part of the everyday work of engineers everywhere. Every solution involves some original thought, some special contribution which we would classify as innovation. This need not be spectacular, it is enough to be new or original.

A spider's way of structure
Open-ended research leads to the most exciting results and stimulus. The spider and the structural engineer share similar requirements and constraints when designing a new structure. The key to the structure of the spider's web lies in its shape and stress distribution. By allowing large elongation of the threads, the maximum proportion of kinetic energy from a flying insect is absorbed as strain energy. The multiple redundancy of the radial threads ensures that the web will function even if many radials break.
A distinct structural hierarchy in the web is defined by the large difference in prestress. Radial threads are highly tensioned compared to the spirals. If a bee hits and sticks to a few strands of spiral thread they break the impact. The load travels from the spirals to the radials, where much of the kinetic energy is absorbed, and then continues straight out to the supports. Meanwhile, the whole web gently vibrates, dissipating energy through air resistance.
The spider is using the techniques of the late twentieth century engineer, but with much more elegance and precision.