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The Computer as an Aid to Better Design

L'ordinateur - auxiliaire en vue d'un meilleur projet

Der Computer als Entwurfshilfe

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SUMMARY

For tension structures, where form is so closely allied to the structures ability to perform, architect and engineer must be able to communicate their individual perspectives to create a total design. Different education and goals makes communication difficult. Computer models which can be developed and used by the whole design team are now providing a common "model" which is the key to improving the communication that is vital to creative design.

RÉSUMÉ

Les structures sollicitées à la traction, dont la forme est étroitement liée à l'efficience, impliquent que l'architecte et l'ingénieur puissent se transmettre leurs propres points de vue, afin de réaliser un bon projet. Mais les différences de formation et d'objectifs d'étude ne facilitent pas ces échanges. A l'heure actuelle, des techniques assistées par ordinateur et utilisables par toute l'équipe de concepteurs permettent de fournir un "modèle" commun, qui représente la clé de communication indispensable pour la créativité de l'étude.

ZUSAMMENFASSUNG

Für zugbeanspruchte Tragwerke, bei denen die Form so eng mit der Leistungsfähigkeit verbunden ist, müssen der Architekt und der Ingenieur ihre individuellen Sichtweisen mitteilen können, um einen geschlossenen Entwurf zu erreichen. Unterschiedliche Erziehung und Entwurfsziele erschweren dies jedoch. Computertechniken, die vom ganzen Designteam benützt werden, können heutzutage ein gemeinsames "Modell" liefern, das den Schlüssel zur Kommunikation darstellt, die für den kreativen Entwurf unabdingbar ist.

At FTL and Buro Happold we have been working for the past fifteen years to develop software which produces a model for the architect, structural and services engineer. At the core of the software is a dynamic relaxation routine which defines a surface form and forms the base for stress analysis of this surface under applied loads. Input of a model requires only the definition of a few key parameters and the geometry of fixed positions along the perimeter. A network of triangular membrane elements is generated automatically and the form (surface geometry) is defined when equilibrium is achieved under a given internal stress pattern - there is a close analogy with a soap film model at this stage. The model surface co-ordinates are stored but rarely need to be known. By attributing "real" values of stiffness to the membrane elements and " real" loads perpendicular to the surface to model wind or snow, new equilibrium state can be defined which give the designers a good measure of the likely deflections and stresses both in the membrane and other key components.

The surface geometry is also vital in providing cutting pattern data for the fabricator, as the skin must be made from a number of tailored panels of membrane to achieve the final curved form once stressed. The fabricator uses the same model as input to his automated cutting table.

The model which serves the engineers and fabricators can now also serve the architect. High resolution screen graphics allows a model to be built up around the defined membrane surface which is an accurate representation of the whole local environment. Rapid refreshing of the image gives the user a "walk-through' option which goes beyond that possible with a physical model. By reading in digitised images, real life and model can be superimposed to give a life like image. At this stage the model can be refined to investigate any combination of alterations to the form of the structure and its surroundings. This has implications for the whole design team, as it is of the utmost importance that they all relate to this central model and are involved with such developments at all stages.

Detail design can again develop out of the core model which is a store of all the geometrical and stress requirements of the structure. Selection of elements from a library of available components allows the rapid visualisation of suitable contributions and to a suitable design choice. Full scale drawings can be output from the model. Component schedules for ordering can be taken off for the fabricator.

Buro Happold has worked with many architects offices in developing tension structure designs for projects all over the world. Recent collaboration with Ron Herron led to the production of an award winning design for an office refurbishment in Central London for the company 'Imagination', including a free-form fabric roof covering a central atrium and exhibition gallery. Heron Associates are in the front line of the development of advanced visualisation techniques for architectural design using relatively simple desk top computers.

The design of the Imagination Building took place in 1988 when the architects and engineers developed their models separately. Communication was by two dimensional images alone.
Since then both practices have developed more advanced software and focused more attention on the easy transfer of compatible data between offices. We are now able to work effectively on a single common model. A surface is developed initially to an equilibrium form by the engineers who can also incorporate visualisation options. This surface model is then transferred to the architect who incorporates it in a more detailed local contextual model with any amount of "paste on" imagery. Meanwhile the same model is developed by the engineers for load analysis and patterning.

Architecture and engineering - a problem of language:

Engineering as we know it today is much younger than architecture. From its start as a profession, engineering was seen as built round a body of knowledge as scientific as possible. This is given to young recruits at University - after all, what are academics for but to add to that central core of scientific knowledge - and then learn how to apply those principles systematically under an apprenticeship to a skilled practitioner.

The architects have taken another view. They have consistently hung on to the concept of education by apprenticeship even within the Universities. The student carrying out project work which is constantly being compared with precedent encourages a broader, less structured approach more related to an education in the humanities, based on scholarship in the critical study of historical buildings.

Thus an architect will describe his aim as "giving one's client what he wants but does not know he wants it" while an engineer can describe his aim as "doing for one buck, what any fool can do for two". An appeal to a broader sensibility by the architect, a pragmatic solution by the engineer.

In this they are reflecting their separate responsibilities. Design is the organisation of building. It is cheaper to think out what you are going to build before you start building it. It denotes both the content of a set of plans to build from and the process of the production of those plans. The process involves tentative layouts of the building and its components, checking of the structure and servicing by numerical analysis and the necessary testing before fully detailed drawings are released for construction. It is a complex iterative process in which the responsibility for the overall drawings lies with the architects, and the responsibility for the performance of the structure and services - together with determining their construction -lies with the building engineer.

Galbraith has written "what is common to most successful technical enterprises is the inevitability of collective decision making and guidance in which specialists participate, contributing the needed knowledge or expertise." That decision making is dependent on dialogue, in turn dependent on enough shared language; understanding not just the concepts but the intentions.

If one thinks about this it is incredibly difficult. Even if the disciplines have the same common everyday language the architects design techniques are primarily visual, the engineers are usually either experimenting physically or analysing numerically. Further to that, there is often a deliberate educational separation promoting differing professional values and mystification. An example of this is that, with the exception of a very few practitioners, those engineers most admired by architects are not the same as those most admired by engineers and vice versa.

The nature of innovation - the development of techniques:

In the complex world of building there is relatively little innovation - and what there is probably develops slowly. But it exists in what we will call "radical design", where either the total solution is new and original or, much more likely, some aspect of the problem is. In any profession there are relatively few practitioners interested enough and able enough to attempt radical design. The building engineering radical usually has to fund it himself. It is rare to be paid to do it. Radical design requires considerable courage since one is "selling" an unproved idea to a client, committing oneself into carrying out an indeterminate amount of original work in the same time or less than would be allowed for a normal design and acceptance of responsibility for construction and performance. If it is a brilliant idea it will soon be used and claimed by others, as design developments in building cannot easily be patented. To be successful at it one has to work at it over a period of time; successful innovation occurs in a series of steps, we are only describing a small one in this paper. The generator is not, we think, primarily commercial but , as Francis Chichester said "it makes life more intense".

If achieving increased efficiency is an engineer's contribution, a radical architect still has to join in it. The risk is probably different as are the skills required and there is still an enormous amount of unpaid work. A new technical solution often leads to a new aesthetic and while change is an important element in architecture (how else will the young architect kill off the old?) there are very strong fashion currents which have a very slow relationship to technological advances. The engineering must bring restraints and a whole range of spatial and planning problems for which there are few precedents. The reward though is that when one looks back at a truly radical building design it will have faults but usually also an immense impact and life to it. It is as though, starting with the strive for economy, a clear pattern or order is produced which is taken down a hierarchy of detail to achieve a sense of organisation and unity.

Such innovation tends to follow a standard pattern. Developments in material science or similar stimulate more understanding. A first design is usually made by physical modelling, with interactive testing being carried out between the small scale and the full scale. Numerical analysis of behaviour will follow but its accuracy only improves as understanding of the scale factors in the physical modelling develops.

All designing is modelling; almost all of it is analogue modelling. It is the "caricature" element of the model which informs the designer. Thus a soap bubble model of a tent shows, nearly, the minimum surface area, with the implications of economy. A tulle model, especially with modelscope photography to remove the scale effect, can express the spatial qualities. And so on.

But such physical modelling is expensive of time and effort, and it is developing numerical modelling which shortens design time, reduces design cost and makes more generally available the knowledge of how to design such types of structure.

Large scale tensile buildings are a relatively recent development providing cheap volume space capable of resisting enormous forces but with limited architectural precedent.

Such tension structures rely on pre-tension in their surface to stabilize them under fluctuating loads and enable the membrane to handle "compression" by a reduction in tension. Generally, the surface is pretensioned against itself, having anti-clastic curvature (saddle forms). The geometry (or form) of this surface determines the way the membrane distributes stresses.

The surface is the structure. There is no distinction between the surface of the building and the skin which carries the loads. The skin defines the architecture. It is this interdependence which brings together the architect and engineer and demands a mutual appreciation of the design opportunities and constraints. The key to this is communication without which the design process fails. It is the techniques developed for communication in the design process which we now wish to examine.

The Core Model: The struggle for an overall technique:

The traditional key to communication in building design is the physical model. In past centuries physical models were often the primary tool for communication. Decisions were made after making prototypes and mock-ups and then translated into drawings. For tension structures physical modelling has long played an important role. Such models bring together the architect and engineer by using materials, such as soap films or woven nylon, which will take up forms that relate directly to the surface stresses. In this way they relate both to the aesthetic and to the technical aspects. The early buildings, where analytical methods of stress distribution were very limited, were built using these physical models. They so clarified understanding that people had the courage to build. The built form so clearly understandable that the buildings are outstanding.

Models such as these which take up an equilibrium form are quite easily built. Models which will tell the engineer the stresses and deflections in the membrane under service conditions - wind and snow loading - are far more complex. Whilst there is still no practicable substitute for a carefully built aero-elastic model tested in a wind tunnel to understand the dynamic behaviour of a flexible structure, the use of computer modelling has become an indispensable and affordable way for tension structures to be understood by their designers. The pace of advance in use of these types of structure will only be set by the capacity of the individual architect, engineer or technician to master and use the necessary design methods efficiently. Most architects and engineers are not model makers but need codified methods.

In tension structures design using physical modelling there has always been a core model as a focus for all communication and decision making. Increasingly it is in a computer rather than on a table, and it is the achievement of this stage in the development of the design method which is being evolved now.

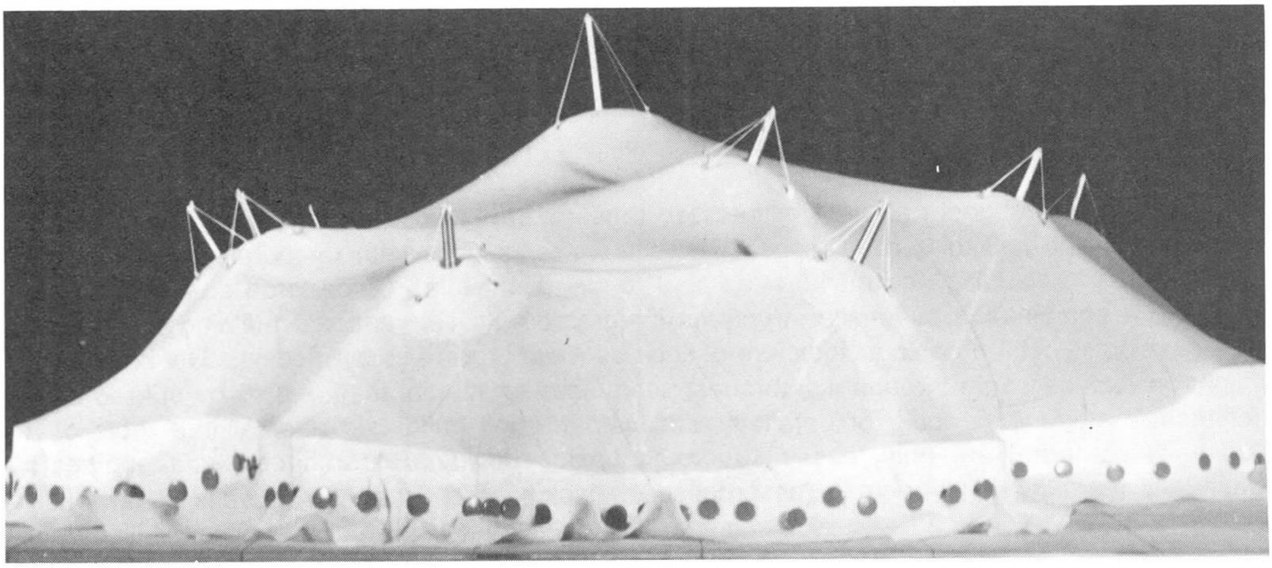

Figure 1: Use of physical modelling

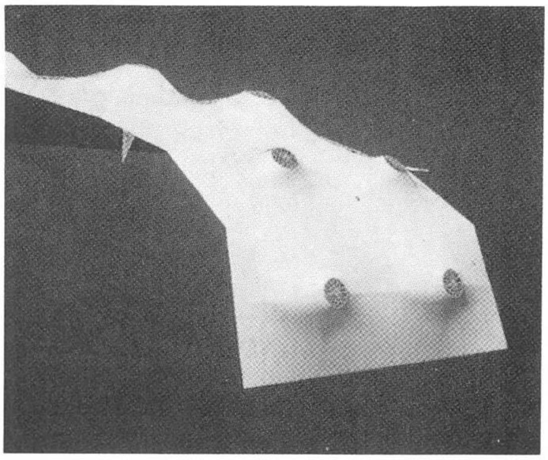

Figure 2: Use of computer modelling

Conclusion

The computer model now offers an ease and speed of interaction which has never been possible with physical models. For tension structures, where form is so closely allied to the structure's ability to perform, a model needs to be adjusted and "tuned" to give the optimum solution in all respects. Physical models using soap films or stretchy membranes are quite effective at providing an adjustable medium to assist decisions on final form. But they do not lend themselves to easy load analysis, accurate measurement or even walk through perspective views. The computer model offers quicker and more comprehensive interaction.

The existence of a single common numerical model does not guarantee free communication or successful design. The design process cannot be reduced to a series of self determining decisions and a single model is nothing if it cannot be both understood and used by those specialists in a design team for whom it has been "built". People need to know how to use the model and what the model will do for them. Different offices need to be able to work with the model simultaneously using their own familiar software. What matters is that all offices and therefore specialists use a common model which can serve all purposes.

It is interesting how the growth of knowledge has occurred. At first there developed a simple awareness of cables, then cable nets with cladding which had different stress-strain characteristics. Form finding techniques by modelling, how to determine loadings by wind tunnel testing and then strain loading wire models. The slow development of numerical analysis methods. Developments in membrane technology and an understanding of modes of failure. The importance of controlling the form and how economics is related to stress levels.

There are rich architectural possibilities for tension structures but the basic shapes are curved; they lead to sculpted buildings. There are associations with temporary buildings, but developments in cladding and membranes start to overcome this. Since large spaces are very economic a combination of tensile structures integrated with conventional building forms start to be developed. The organic architecture of such as Aalto provide study models. The complexity of light on surfaces, light through membranes, seam lines on membranes and so on start to send architecture students to look for parallels with historic shell buildings; after all the roofs of a mediaeval cathedral are only tensile structures upside down. So architects and engineers continually learn more to bring to the process of design. The scale of success is obviously related to how well we can interact our separate knowledge, experience and sensibilities. It must be through some form of "core modelling". Then not only are our possibilities extended but we can also develop more clearly the art of our time.