The work of an architect in the digital age has become easier and faster in most cases and the new tools provide more choice and freedom in the whole working process especially in the form finding process. Firstly the method of finite element analysis has given the architect and the engineer a quick method of defining a configuration and means to project it into a sort of virtual reality.

With these digital methods the form finding processes can be developed to form an integral part of the designers work resulting in objectively optimised constructions that are not anymore the result of an artists arbitrary will but mathematically and structurally sound forms.

This does not mean that there is no creative talent necessary anymore, on the contrary, because now the artist is able to manipulate and stimulate a process of form finding that ultimately results in a high quality product and eventually an aesthetic one, rewarding him for his work.
1 DIGITAL TOOLS IN THE DESIGN PROCESS

The traditional design process in the past was a making of forms by a creative artist who would dictate the materials used in his architecture to the places he decides to become his art work. This seems to still hold true for many architects in the digital age where they seem to have even more freedom to “create” art works with modern tools that allow more control and especially more visual realisation of how a building is going to look in future. Lightweight structures and especially membranes follow another way. They cannot be designed by an arbitrary act of an artist but only by a scientific process of form finding. In the early days of lightweight structures these processes were realised by material models. In front of everything soap film models, that were not only difficult to make but also difficult to document. From the initial soap film models, that were photographed in parallel light more durable models were made using wires that were soldered in nets with real edge cables into forms of equal surface tension by measuring and soldering again many times until the form was sufficiently good.

A very tedious process which yielded imprecise results from which again, with very imprecise methods, measurements were taken for the loading and structural calculations made and ultimately the production drawings.

By using computer programs, this method has undergone a revolution and form finding processes have become more and more accessible and realistic. Firstly the method of finite element analysis has given the architect and the engineer a quick method of defining a configuration and the means to project it into a sort of virtual reality. Several fundamentally different ways have since come into reality competing for best results. To make these methods accessible even for architects with a limited knowledge of numerical methods was the aim of “Delite”, a European Project (European CRAFT Project, Contract Nb. BRST.CT98-5166). The short coming of these methods however was always the fact that wind loads – basically the form determining load cases had to be found by expensive wind tunnel tests or estimated based on some very insufficient codes from the 19th century.

Computational Fluid Dynamics has now the same revolutionary potential as FEM used to have and we are in the process of developing a module to be used in conjunction with “Delite” to make this accessible for designers as well as engineers (coupled programs). With these digital methods (multi physics) the form finding processes can be developed to form an integral part of the designer’s work resulting in objectively optimised constructions that are not anymore the result of an artists arbitrary will, but mathematically and structurally sound forms. This does not mean that there is no creative talent necessary anymore, in fact the opposite, because now the artist is able to manipulate and stimulate a process of form finding that ultimately results in a high quality product and eventually an aesthetic one, rewarding him for his work.

The work of an architect in the digital age has become easier and faster in most cases and the new tools provide more choice and freedom in the whole working process. But they are not a substitute for the primary creative design process. Really perfect 3D presentations give the building, at an early stage of the design process, a virtual perfection that it may never reach in reality after it has been built. This fascinating virtual reality often leads to a situation where the presentation seems to be more important than quality and intention of the design. User guidance, user friendliness and capability of the used program could
lead to forms and designs that can be easily produced with this program. But they exclude other forms and designs which are necessary in case there are difficulties in the realisation resulting from the software used. This could perhaps impose a limitation on the variety of forms and designs in cases of only an elementary use of possibilities provided by the program. And, not to forget, the representation in the drawing and on the monitor in reality has always only two dimensions and not three.

Digital tools are helpful in the design process and the work can be done more efficiently and faster, and especially the internet allows a fast and direct data transfer and an interlacing between all participants even over long distances. But at the moment not all of the mentioned tools and processes work without problems. For example, the data transfer can not be done without problems. Different programs with different data formats and standards make it difficult to interchange information and can create errors by transmitting or converting the information. Today there are too many "island solutions" that make the interlacing more difficult. To get a really efficient design process in the future all the information has to be organised over a central data backbone to which all participants have access. There should not only be a data backbone for interchange, there should also be a dynamic interlace. For example, a change of the dimension of a mast should initiate a reaction in terms of the statical engineering, a change in the bill of quantity and changes in the drawings. Where the automobile industry with its "product lifecycle management" is advancing architecture stands at the beginning of this process.

2 PRELIMINARY DESIGN

The adaptation of the design idea begins with the hand sketch. Then, with the help of a CAD program, this sketch becomes the first digital form. At this stage, the mean measurements and dimensions have to be defined because the working CAD tool needs a numeric input. Until a few years ago the design of membrane structures in a digital way was not easy and there were many problems to be solved. The early programs needed at the beginning of the design process a huge number of definitions to start the form finding process. With new user-friendly programs it is easy to create a first simple form with the computer quickly. As a basis for this digital input of the geometry, initially only the edges, high and low points are needed.
This input can be made with a CAD program, e.g. AutoCAD, which provides the digital data for the first step in the form finding. A FE-program, e.g. Delite/PAM Lisa, takes this data and leads to a first form and to preliminary forces. An adapted finite elements program calculates a uniformly stressed minimal surface in combination with the structural elements, e.g. arms, masts, cables.

With some experience this first form finding can be done very easily and fast. This is a relief compared to older methods but it cannot replace these methods completely. Soap film and silk net models are real 3D presentations but they need a lot of time and material to make and it is not easy to transfer the geometry and the results of the form to the drawing quickly. Experience in finding forms with analogue models is fundamental and necessary in order to get an understanding of and feeling for the form in the digital design process.

The geometry obtained by the digital form finding can input directly into the CAD program. There the work can be continued with other programs and tools. At this early stage of the design process the structural and aesthetic characteristics of a variety of different alternatives can be checked. With the help of the digital tools the designer can determine the appropriate structural form and so manipulate variables such as the plane form, the 3D surface, dimensions of the building parts (e.g. cables length, size) and the direction of forces. Preliminary lighting designs or climatic simulations with CFD programs can complete the first stage in the design process. The first results can then be put into an illustrative presentation of the design using a 3D program, e.g. 3D-StudioMax.

The designer has a broad choice for the presentation, from the "simple" rendering with textures to presentation in the cyberspace, as is possible in the "cave" of the IPA at the Fraunhofer Gesellschaft. These digital tools make it possible, at the preliminary design stage already, to produce an almost real presentation of the building.
3 DESIGN DEVELOPMENT

Form finding, the structural analysis of membranes, the production of cutting patterns and working drawings are all carried out on the computer through the application of CAD-linked finite element programs and coupled fluid dynamic programs. The use of these digital tools allows a verification of the geometrical form, the effects of artificial lighting, the casting of shadows and the selection of materials. The detailed form finding process begins with detailed information about the material, the geometry and the external loads. The input of the material data makes it possible to get, for example, detailed data on the deformation in different load cases. The material data can be obtained beforehand with tests or with some digital methods. For example, there are three ways to get the wind loads. Firstly, the $c_p$ figures and data in the DIN, or in some other standards, can be used to get the statical calculations but this is only a coarse simplification.

Secondly, wind tunnel tests can be carried out, which will show load distributions over the surface. But the model used during the test is a simplification of the form and it is rigid. Normally the result is only the maximum value without any temporary or spatial distribution. And there is a high expenditure of costs, time and material for the experimental set-up and the test evaluation. Thirdly, it is possible to use CFD programs, e.g. PAM-flow, to get exact chronological and spatial distributions of the maximum values. In connection with FE programs the deformation can be used in the calculations. Realistic results based on dynamic behaviour are thus possible.
This result allows an optimisation of form and material at an early stage of the design process. It is then easier and faster to design a building optimised in form and material. To get the material parameters, e.g. modulus of elasticity and extension, it is necessary to do tests to obtain these values. They can be input into a digital data backbone for evaluation and processing. With the increase of entries in the data backbone, the possibilities for finding the needed values in the data backbone increase too. Then these values can be transferred into the FE program and the number of material tests can be reduced.

For detailing the building, it is possible to take existing detail solutions out of a database and thus to reduce the time of planning. Also industrial products, e.g. shackles and end fittings can be integrated in digital form into the drawings. In this way the details match the geometrical and static requirements and can directly be controlled by the engineers. The materialization takes place in the computer and, for example, a membrane edge is changed from an abstract drawing with system lines and points into a detailed edge solution with dimensions and defined materials.

By assembling all details and parts in virtual mode in the computer in a 3D model it can be checked if all the parts fit together. Especially for membrane buildings with their difficult geometry and details, this can be very helpful. The real length, e.g. for cables and other parts, can be output from the geometry of the 3D model with consideration of the details.
The erection and assembling in space can be simulated and if there are any problems with any parts they can be solved in the office already and do not have to be solved later at the building site. The 3D model could also be the basis, for example, for the lighting engineer and for his simulation program for the checking of different proposals for the light and shade under various conditions. Or the climatic engineer with his CFD program can simulate, for example, the airflow with different temperatures in the building. The results or requirements depending on the studies could lead to changes in the design.

4 FINAL DESIGN, PRODUCTION, ERECTION

The results obtained during the early design phase are then detailed and improved to become the final information for the production. The generated data allow a direct link to CNC-controlled manufacturing machinery, e.g. milling machines, laser and water-jet cutters and 3D printing devices. Dimensions, areas and weights of the different materials and parts can be obtained from the CAD program and can be input directly and digitally into the AVA program to get the bill of quantities and the papers for the requests of tender. This information can be given digitally to the manufacturers. A steel company, for example, can take information on the steel parts from the drawing and enter them into the program of the laser cutter or the CNC machine. One of the most important steps in the design process of membrane buildings is the patterning. With the FE program, e.g. Delite/PAM Lisa, the patterning is made based on the form. After the input of the position of the seam lines or the beginning of the fabric and its width, the program creates the particular patterns. The program generates the evolved surface to get the optimal location of the fabric strips determined on the 3D form of the membrane.
The position of the seams and the weave of the fabric (warp/weft) are important for the construction as well for the appearance. For static reasons it is important how the weft and the warp direction of the membrane are arranged. For the design it is important how the membrane area is structured.

For example, it is a difference for the construction as well for the design if the seams around a single mast tent are tangential or radial. The pattern is compensated after the pattering based on the material data. The cutting patterns are given to the manufacturer digitally, so that information, like seam addition, necessary for the production can be added. The digital patterns are nested by a program on the web to minimalize the material utilisation. The data are then transferred digitally to a cutting plotter.

Other steps like shop drawings, orders, cost control, and modulation between the parties can also be done in a digital way. The erection can be more efficient by using material and detail lists, exact part identification and time tables in a digital way like a data base. Especially for mobile or convertible structures it is necessary to have a well planned erection. For mobile structures there is a special and defined way to erect the building, to find all the parts and to erect the structure in the planned way. Convertible structures are complex buildings with sensitive parts, e.g. the drive mechanism and controls, and they need to be assembled very carefully.

5 BUILDING

The facility management can be done by using programs and using the digital data from the planning process like the bill of quantities. Maintenance and repair work can be done more efficiently if there are complete data, e.g. drawings, material lists. Even the demolition of the building and the recycling or disposal of the material can be planned at the same time as the erection based on the digital database, which stores the exact information about the number of parts and the mass of the material.
Architectural Design Process with Numeric and Digital Tools

**Fig. 10 Diagram process**
CONCLUSIONS

Planning is the task to create a harmonic relation between people, nature and technology. Technology is a tool of man, a product of the natural object man and thus also a part of nature. We use technology as a tool that is compatible with nature to be a part of the nature, of the whole. In this way a lightweight structure is not only a technical building it is much more a designed one compatible with nature.

To rely on the technical side alone often leads to unsatisfactory solutions. And the question should be asked, if all that is possible and feasible in the virtual world makes sense and is beautiful in the real world. A lightweight construction is more than a building with less weight. A lightweight structure should have a charismatic lightness compatible with nature and a harmony of its own. Construction means bringing things together, building them. All material objects are constructions. They consist of parts and elements that interact with each other and this should be kept in mind in spite of all the technology that is in the foreground today.

Lightweight structures have to seen from a holistic point of view. This means an interlaced design process with deference to all involved participants and parts. The design of a lightweight structure is much more involved in all parts of the building process, especially the construction, than the design of a normal building. For this there is a high complexity and relation of the different parts and they could not be exact and analytic and separated in single parts, independent from each other. The complexity increases with the increase of the number of involved parts, e.g. facade, insulated roof. A change of the form and shape can lead to a change of the structure and so to changes in the dimension of building parts and also to a changed light distribution in the building. Digital tools can help to optimise the complex design process today and in the future. Different parts of the design process can be interlaced and can lead to more efficient work and finally to a good and beautiful building.

But the essential thing is the design idea or intention. It is much more important than the technical design. Digital tools can help the architect but they cannot do the real work.