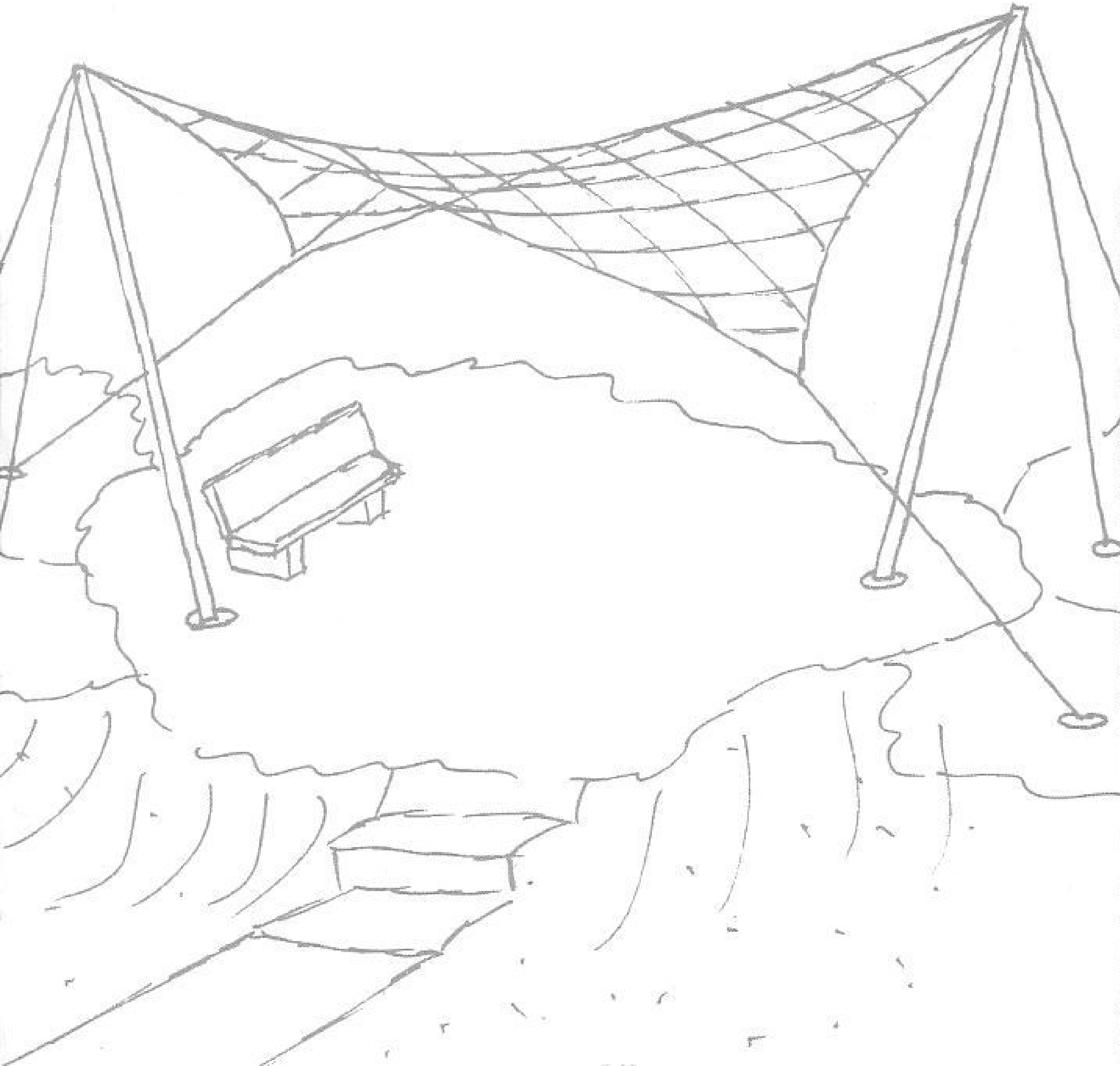
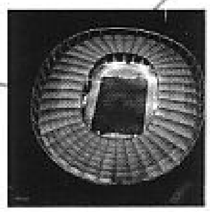
Guide to textile Buildings

An Information of Working Group For Textile Architecture





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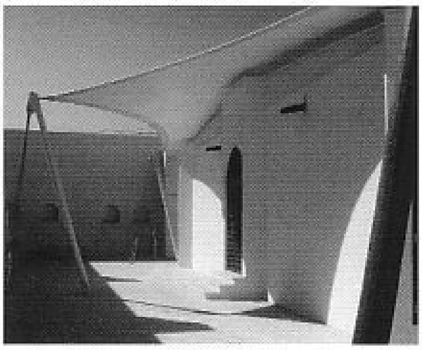


Introduction

The present brochure "Guide to textile buildings" addresses general and commonly asked questions regarding textile building. It is intended as a guideline for all interested persons who are dealing with this subject. We are not only thinking of architects, engineers, planners, principals, etc., but also of students at universities and institutions of higher education.

We want to contribute to reducing any information deficits that may exist and further promoting the confidence in building with textiles.

Textile building combines creativity and aesthetics with resource-conserving materials utilization, short construction periods, long life and low costs. State-of-the-art technologies and innovative textile materials allow large projects to be executed in combination with or as an alternative to non textile building materials.

The contents of this brochure was developed by the members of the Working Group for Textile Architecture. It is backed by competence and experience from the fibre and coating material to production of the textile membrane to the textile building.

Working Group for Textile Architecture

Michael Jänecke
General Secretary

April 2002

Building with textiles has a development potential, the like of which we only expect for the building material glass. Nevertheless, our design process should leave the goal of a smooth, taut, monochrome skin and return a quality to textile building that has been lost: that of fabric.

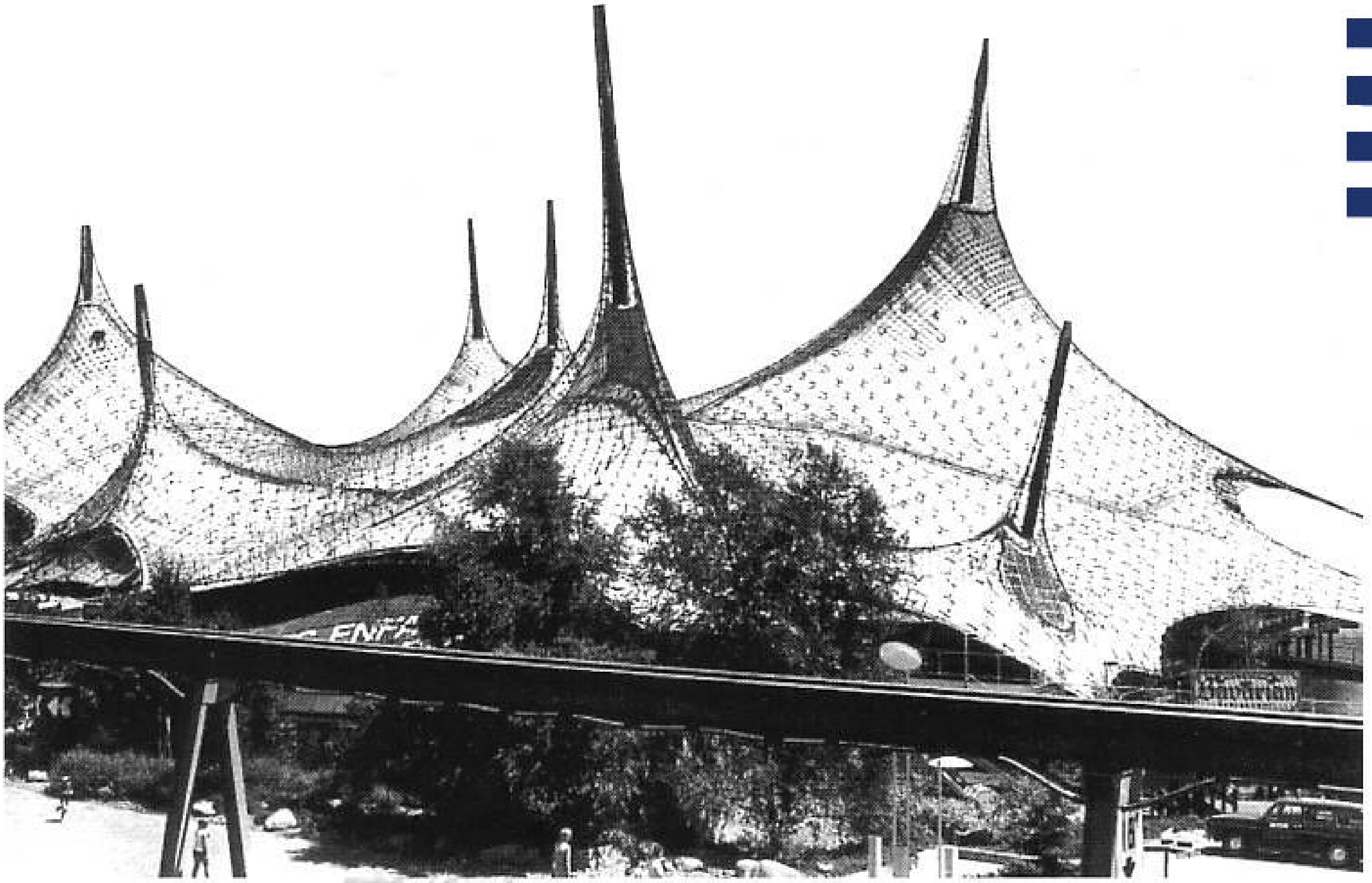
Prof. Dr. Ing. Werner Sobek,
Stuttgart, Germany

Materials have always played a critical role in our architecture. We pursue an ideal tht one might call 'truth to materials' where the structure is both appropriate and evident, the details are self explanotory and the primary constructed surfaces remain visible in the finished building. Increasingly we are exploring highly efficent, multi functional elements, where structural performance, enclosure, light and thermal transmittance arê combined in a single element.

In all of this we seek an architecture that is of our time and that lifts our spirits.

These are the reasons we use membrane structures in some of your buildings. Standing beneath the undulating and taut canopies high overhead, one is aware of the perfect diagram of forces, the precision of a handcrafted objekt and a sense of light that is perhaps this century's response to the grace of the Gothic cathedral and the bravura of the Crytstal Palace.

Sir Michael Hopkins,
London, Great Britain

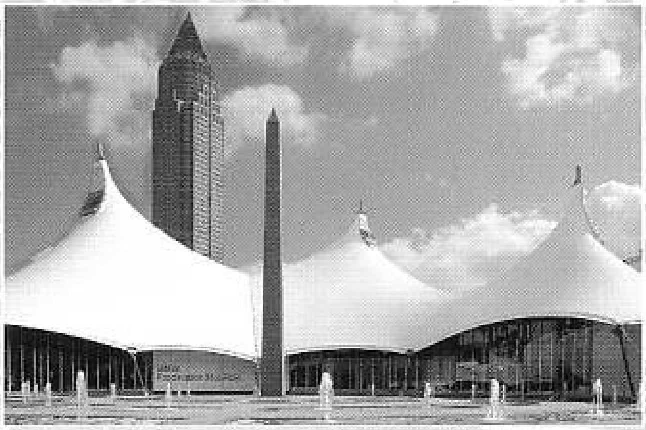


Achieving increasingly more with less and less - this requirement of our time is met in an exemplary manner by textile structures. They draw on the origins - the ancient form of the tent is ever-present and yet, the best achievements appear to come to us from the future.

No other type of architecture benefits from its primary conditions in as direct a manner, in none other does the shape follow the function as rigidly, none other achieves as much span with as little material and energy expenditure, while conserving resources in the same manner.

Short building times, cost-effectiveness, urban development qualities and long life make textile structures appear to be the chance for a new type of architecture for mankind and its environment.

Manufacturing hall,
Airbus, Toulouse, France



BMW exhibition
pavilion at the
IAA 1995–1999
Frankfurt/Main,
Germany

Textile Building

Development yesterday, today, tomorrow

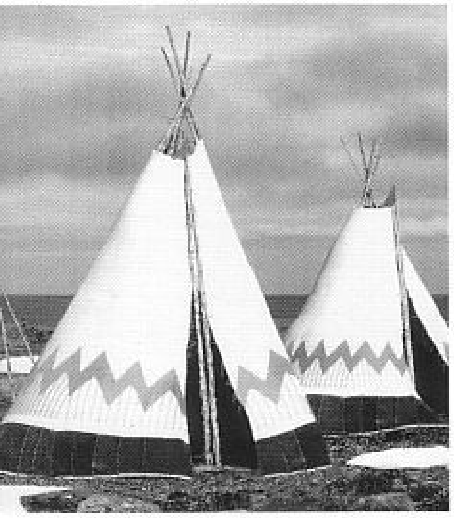
The history of tent-type housing is as old as mankind. Leaves, bark, leather and felt all came before fabrics.
The advantages are unchanged: ease of erection, simplicity of means, high mobility.
This compares to extreme complexity of static forces.

Only two decades ago, complex models were used to find the form, to establish the load bearing performance and to study the stability.

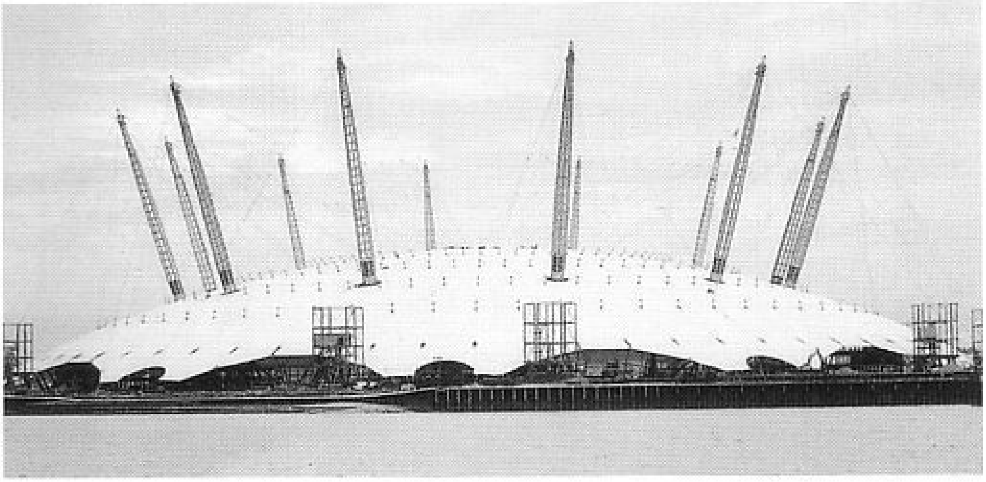
Today, computers are not only used to design the spatial vision and to calculate all loads, including snow and storms, but also to define the cut of textile segments with millimeter precision.

Tuday:
Daimler stadium,
Studgart Germany

Textile buildings develop in an increasingly futuristic direction. There is an extremely varied range of possible applications: industrial and commercial buildings, sports facilities, roofs for shopping streets or trade fair/exhibition halls; architectural fantasias and visions are no longer utopian.



Yesterday:
the beginnings of
textile buildings



Tomorrow: Millenium Dome, London Greenwich, England

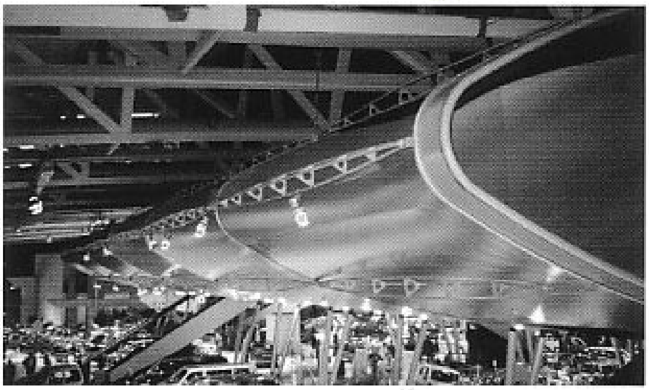
Applications of Textile Building

Shopping Malls

Shopping center Marler Stern,
Marl, Germany

Shopping center Forum,
Kirchberg, Luxemburg

Exhibition and event building



Exhibition pavilion,
German show'
Tokyo, Japan

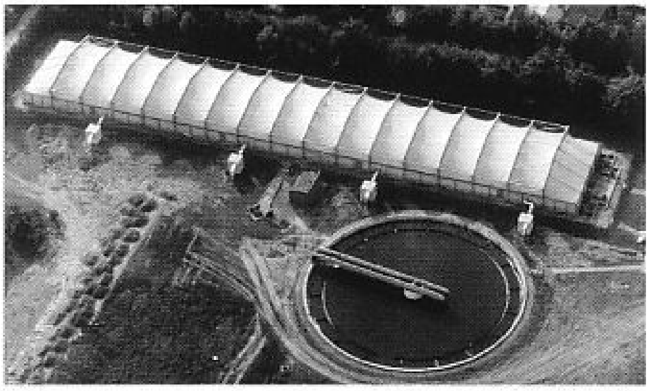
Event pavilion VW,
IAA 1997, Franfurkt/Main, Germany

Sports facilities

Mobile membrane roof, Center court, Rothenbaum,
Hamburg, Germany

Ice skating hall,
Goppingen, Germany

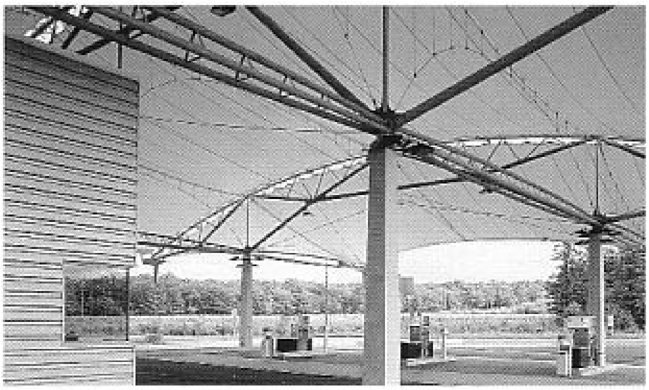
Environment



Water treatment basin roof,
Hardarwijk, Netherlands

Water treatment basin riif,
Helingen, Germany

Transport facilities



Denver International Airport
Denver, USA

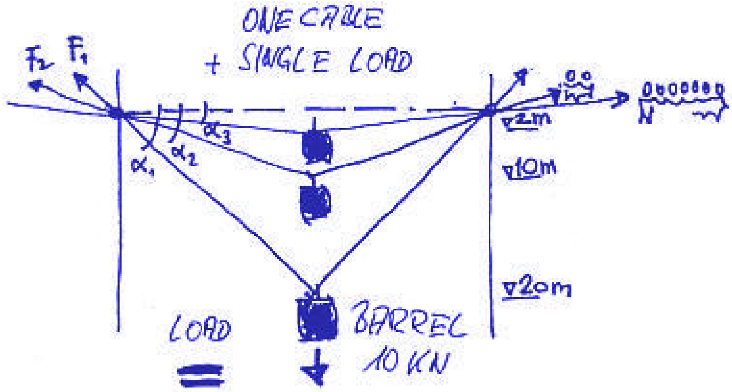
Fina Petrol Station,
Wanlin, Belgium

External loads generate forces and stress in the system

1. Thrust and force

Example 1: To pull a barrel of 10 KN from a depth of 20 m to 10 m, we require 7 KN at the right and left side, i.e. 2 men, each pulling with 3,5 KN. To lift this barrel 8 m higher, we require 26 KN per side, i.e. 26/3,5 gives 7.5 men per side. This is yielded by the formula:

=F = Load/2/sin Alpha



2. Suction

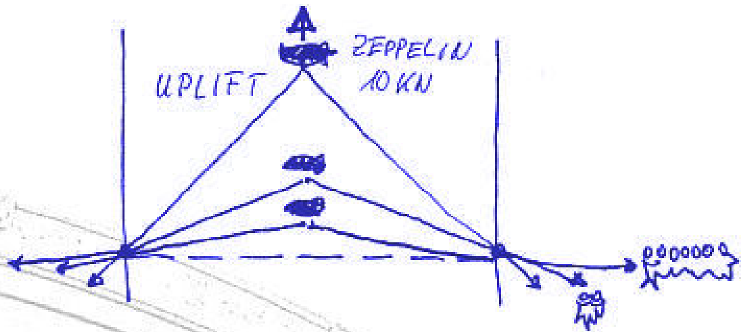
If we turn the load direction and consider a zeppelin, which we wish to draw down from 20 m height to 2 m for landing, we can apply the same observation as above.

We are now dealing with an upward force, generated by the lift of the zeppelin.

We call this upward force SUCTION.

Same formula as above:

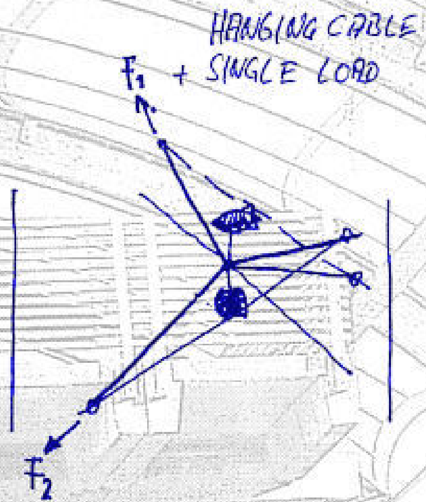
=F = Load/2/sin Alpha



3. Single load on a cable

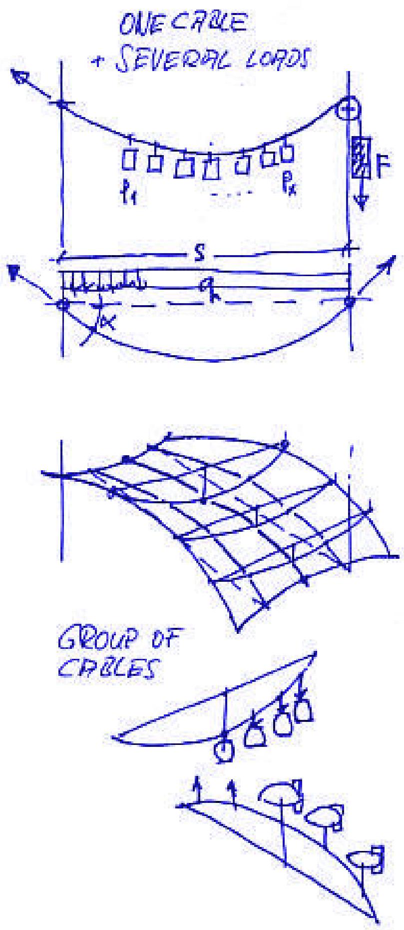
If we combine the two force directions and consider a hanging cable, then we have a downward force from external loads, like our barrel, and an upward force, like our zeppelin.

The two force directions generate resultant forces at the end of the cable, which can be divided into x- y- and z-components



4. Several loads on a cable

If we suspend, as in the case of a cableway several cars on one cable the whole cable then assumes a polygonal course and forms a cable parabola (approximated by a circular segment). The calculation formula for the forces at the end of the cable looks like this:
= **load*sag/2/sin alpha**

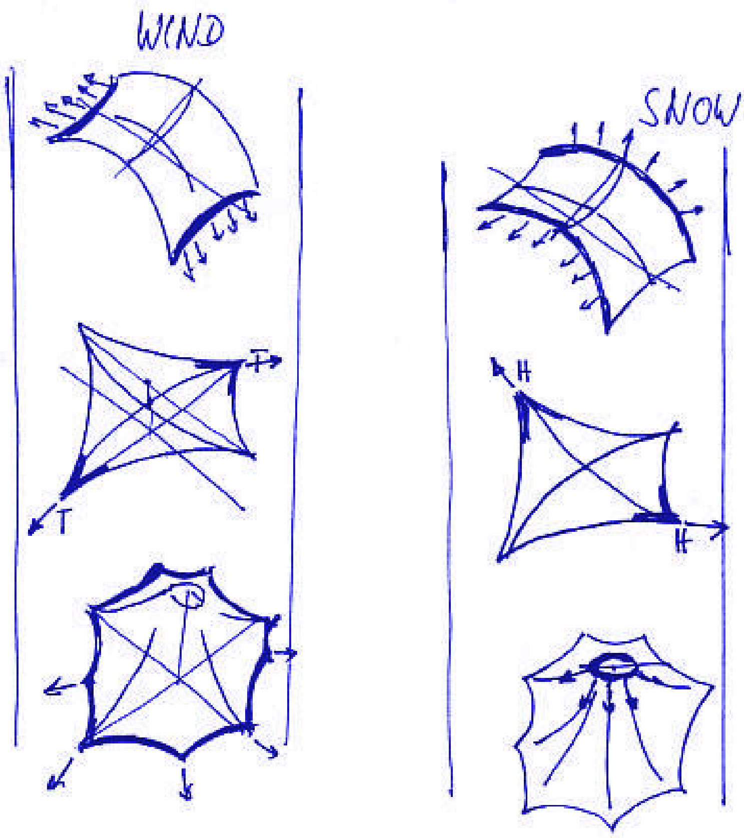


5. From line to surface

We now transfer these observations from the LINE to the SURFACE. We consider, instead of the one hanging cable the SURFACE (simplified by a cable grid) of a saddle-, a hyperboloid- and a high point-geometry.

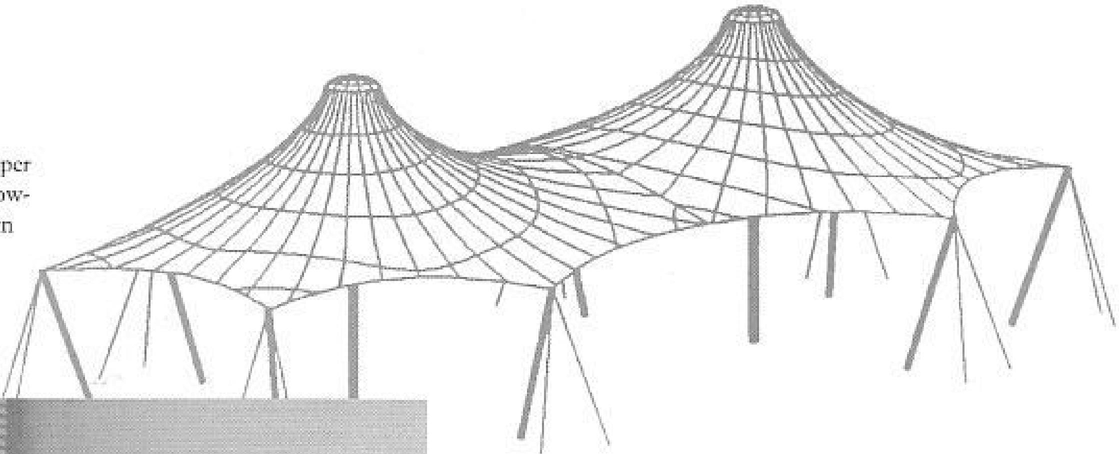
We further change the observations from BARREL and consider the SNOW load, and we change the uplift of the ZEPPELIN into WIND load.

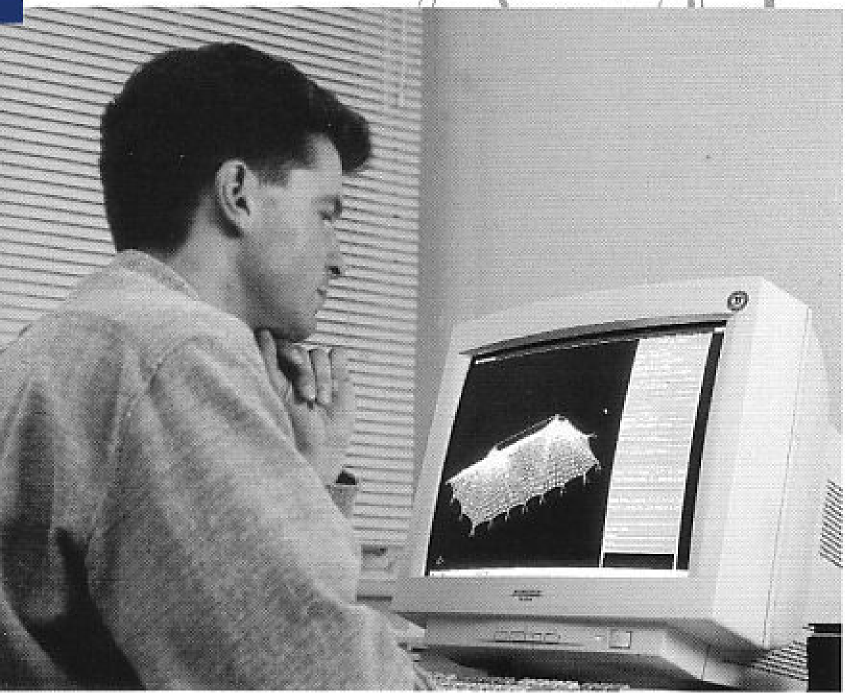
The diagrams show the reactions in the surface of the different geometries from wind and snow. Dark shaded places with the arrows indicate the reactions in the membrane from wind and snow loads.



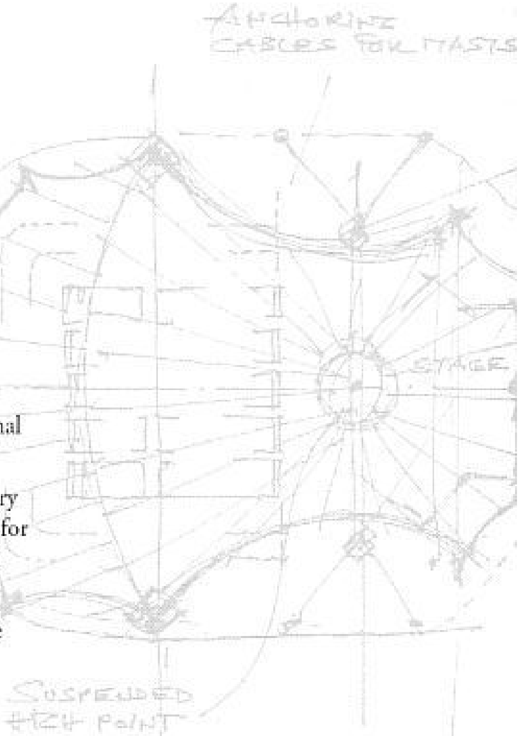
Draft/Design

Close cooperation of all parties involved - principal, planner and/or engineer and membrane manufacturer - is required at an early time to create an ideal, aesthetic, proper and economic roof. The following procedure has been shown to be best:

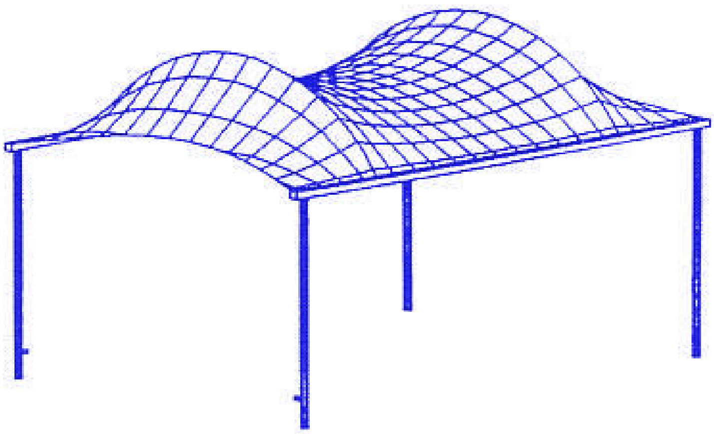




Special software programs assist the architect and engineer in their implementation of ideas



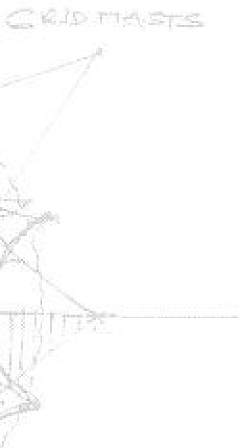
- The first sketch of the architect defines the basic conditions, which are the result of functional requirements for the planned roof or the desired optical effect.
- This is developed by the specialist engineer of the membrane manufacturer into a preliminary draft which includes both the necessary geometric shape and the necessary design elements, for example the positioning of supports, suspensions, anchors, etc. A budget can be determined from this draft.
- Together with the architect and the principal, this draft is used as the basis for designing the final shape, the planned aesthetic aspects, functional requirements and the planned budget.



Textile building is a very demanding style which can only compete with conventional structures due to the aesthetics that can be realized by meas of it. From a business point of view, relative to the cost per sqm of roofed area, its position is between conventional roofs of steel or sheet steel and glass roofing. Hence, it cannot be compared in the least with cheap tent roofing. From an ecological point of view, textile building has the advantage over all conventional styles that only about a third of the usual design weight is needed.

Load

In contrast to conventional structures, the final shape of textile roofing is only determined by static calculation.
This means that the design planning must be performed in close coordination with static analysis to achieve an optimum economic and design concept.
Based on the long life of materials, textile roofing can today be classified as permanent structures, like conventional buildings. In accordance with the standards of individual countries they therefore require approval and must correspond to the load assumptions made in the pertinent building statutes. Regional requirements, such as wind and snow loads, must be taken into account, just like the climatic conditions of the intended site.

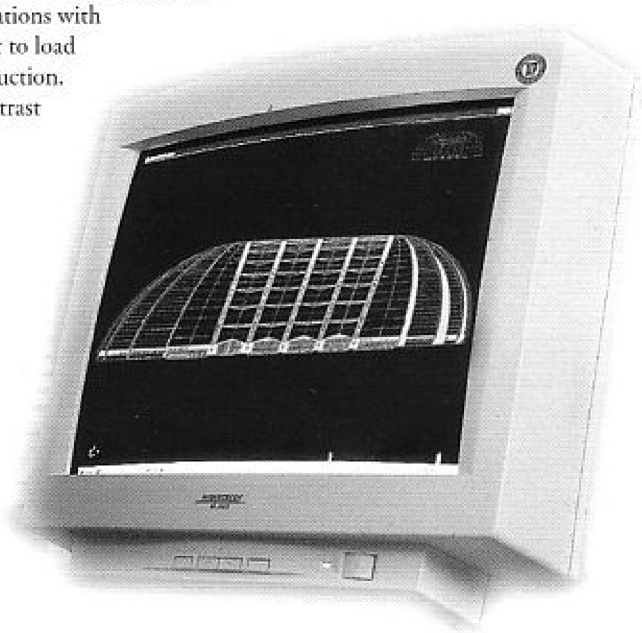


Statics

The static calculations themselves are based on the data described above, which are the result of the form design. The final static calculation, which is capable of review, is performed during comprehensive calculations that must take into account the three-dimensional nature of the roof and the biaxial elongation behavior of the material, beside the various loads.

The static characteristics of the membrane result in the requirements for the overall detail design for the textile roof. The edge geometry and edge design, which support the loads, are defined during this process. This also applies to load introduction points in the supporting structure. It must be taken into account that textile roofing will change its shape under external loads (for example wind or snow). These loads must be accepted by the connection points to the building, to existing conventional buildings or the introduction of forces into the foundations.

In contrast to conventional buildings, the dead weight of the material (approx. 1 – 1.5 kg/sqm) can be neglected. This results in high susceptibility to wind loads, which is balanced by the static equilibrium of a membrane structure due to its shape and preload, but which makes special requirements for the supporting structure and foundations with respect to load introduction.
In contrast to conventional building, the load-bearing capacity of the soil is decisive for foundation dimensioning only in rare cases. Dependent on the soil conditions, tensile loads can be accepted by heavy-duty foundations or by special ground anchors.



Engineering

Ultimately, the static calculations define the required tensile strength of the material.
A combination of structural steel and cables is generally chosen as the supporting structure. The design can be chosen freely, provided that the geometric and style-specific connection points are taken into account.
Based on the optical lightweight character of the roof, it is an obvious choice that, for example, supports and beam systems are broken up into filigree trellis structures or are replaced by cable structures as far as possible. Of course, supporting structures of aluminum, stainless steel, glued wood or reinforced concrete are also possible.

After approval of the static calculations by the building authorises, the design drawings are prepared. Primarily with a view to design elements, they must be discussed with the planner and the principal.
It is important that, along with accurate geometry of the membrane, an adequate number of attachment points for erection and tensioning tools is provided. Generally, the supporting structure and the membrane are completely prefabricated at the works, similar to prefabricated housing.

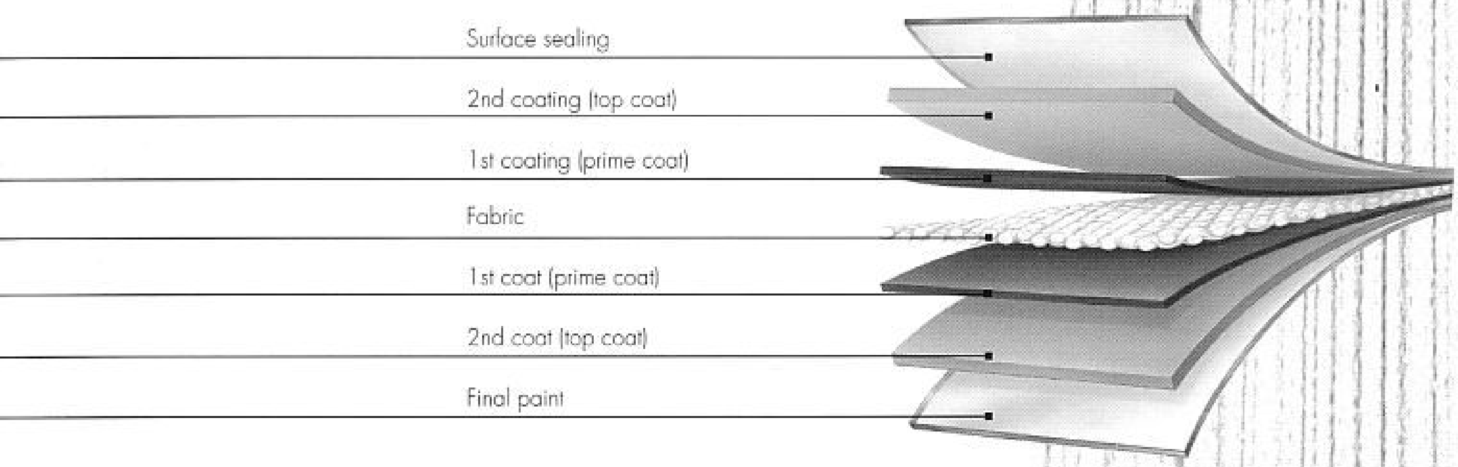
Textile Building Materials

The material types described below are standard products that are used for far more than 90 % of all textile roofs. Approximate values are given in all cases.

With respect to the soiling behavior, but also to life, various final surface paint coats are possible. Acrylic paint is offered as a standard. PVDF paint results in a significant improvement of the soiling behavior.

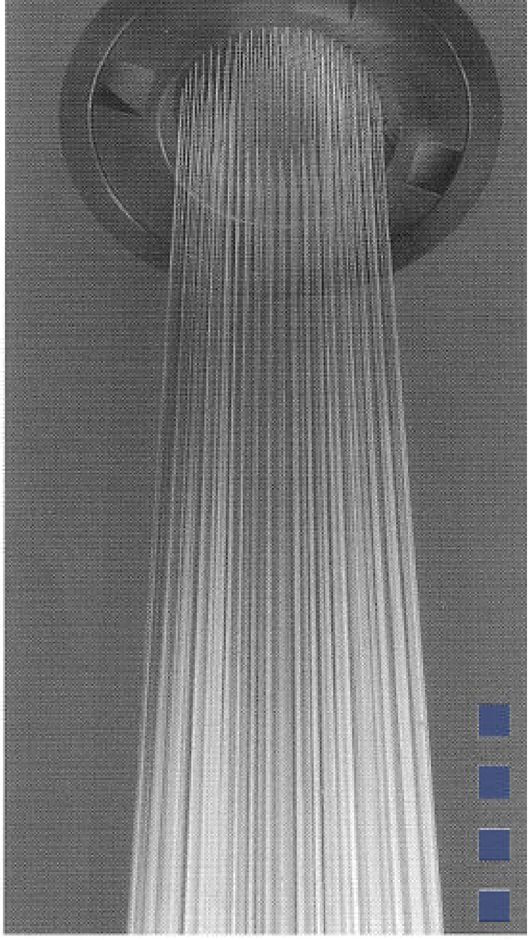
Classification of membrane types of plastic-coated polyester fabrics

	Typ I	Typ II	Typ III	Typ IV	Typ V
Threads in warp and shot	9/9	12/12	10,5/ 10,5	14/14	14/14
Yarn fineness (dtex)	1100	1100	1670	1670	2200
Total weight (g/sqm)	800	900	1050	1300	1450
Tear resistance (N/5 cm/warp/shot)	3000/ 3000	4400/ 3950	5750/ 5100	7450/ 6400	9800/ 8300
Resistance to tear propagation (N, warp and shot)	310/350	520/580	800/950	1100/ 1400	1600/ 1800
Hard flammability	jes	jes	jes	jes	jes

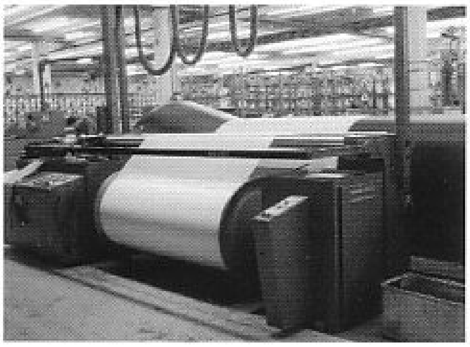


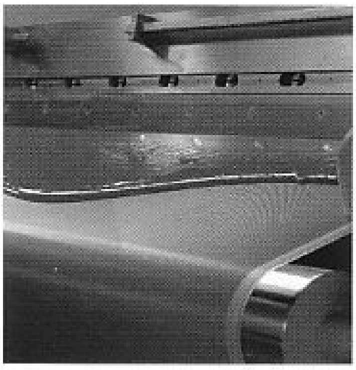
Hihg-quality membranes are composite materials for extreme requirements

Along with plastic-coated polyester fabric, PTFE-coated glass fabric is also used for certain applications. A comparable range of materials is available here. The following overview attempts an assessment of the various materials under different aspects. A general decision based on the table below will hardly be possible, however.

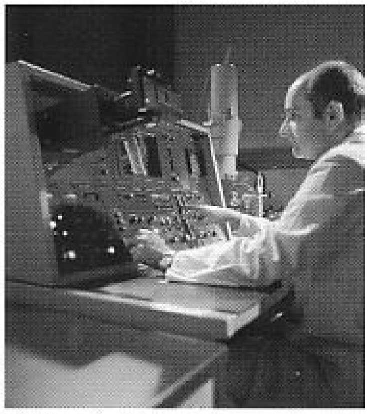


Spinning nozzle for technical chemical fiber production





Coating and sealing of fabric



Continuous quality control is a matter of course

Properties of various material types

Fabric	PES/PVC Acrylic finish	PES/PVC PVDF finish	Glass/PTFE
Average life	10 - 15 Jahre	15 - 20 Jahre	über 25 Jahre
Weather resistance	xx	xx	xxx
Soiling behavior	x	xx	xxx
Translucency	xxx	xxx	xxx
Fire behavior	xx	xx	xxx
Kink resistance	xxx	xx	(x)
Cost basis: 110	100	110	200/250
Applications	temporary and permanent buildings	temporary and permanent buildings	permanent buildings

Assessment classification:
(x) = unsatisfactory; x = satisfactory; xx = good; xxx = very good

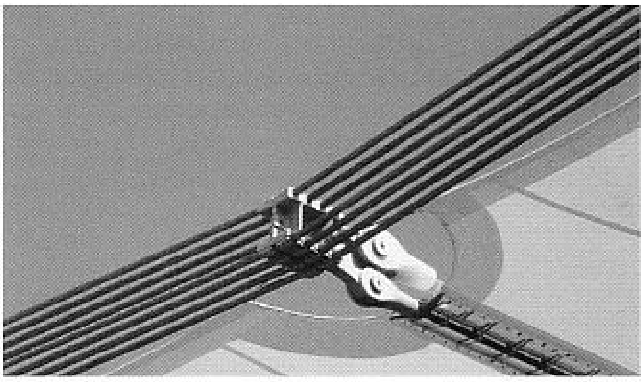
Elements of supporting structures:

Supporting structures of steel

Supporting structures of steel are used for textile building in most cases. Steel structures offer the greatest freedom with respect to the integration of suitable connection fixtures. Using different steel grades, they can be designed as heavy-duty but filigree structures. And, like the membrane surfaces themselves, they can be prefabricated at the works ready for erection.

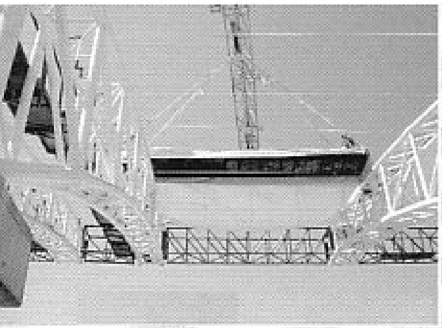
Primarily pipes and welded structures are used that are designed according to the load, but also based on design requirements.

Standard sections commonly used in structural steel building are less suitable, because they are frequently not in line with the special requirements of a textile roof, or because they appear ungainly. Structures of stainless steel or aluminum are also possible. Both the development of the shape and the engineering design must pay special attention to the material-specific characteristics, however.



Typical edge cable structure

Supporting structure of steel and cables



Filigree steel trellis beam of a sports stadium

Alternatives

Primarily for the use of parallel or symmetric structures, supporting structures of glued-wood beams offer themselves. As they are designed to accept high vertical loads, a combination with steel elements accepting the tensile forces is always required. In order to avoid corrosion problems due to condensation, adequate ventilation must be ensured whenever wooden structures are used.

Supporting structures of concrete are also possible. In this case, one restricts oneself to the basic structures in order to avoid destroying the impression of light weight in the membrane roof by massive supporting elements.

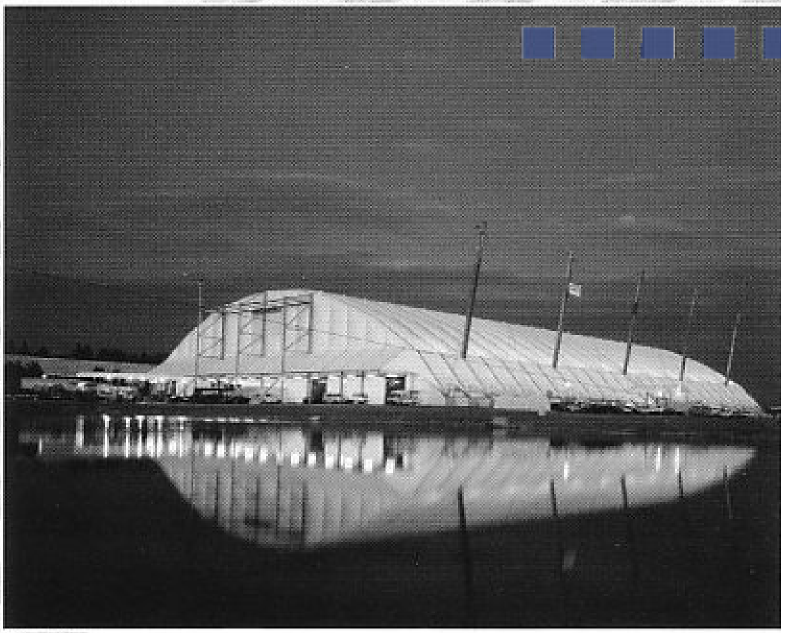
Supporting structures of cables are ideal (generally combined with steel supports, etc.). They have a filigree character, can be subjected to tensile load and their system is related to that of textile roofing. Cables can follow the shapes and shape changes due to external loads that are inherent in textile building. Cable nets can be used to statically support membrane surfaces and thus allow even greater roof spans without supports. In most cases, flexible spiral cables of galvanized design are used. For example, they are used as edge cables, carrying cables, tensioning cables for supports.

Glued-wood beam structure, covered walkway new-business center, Straubing, Germany

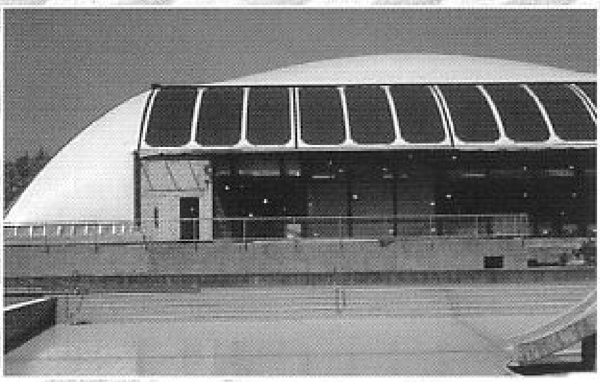
Air

As described above, air can also be used as a supporting element. Air pressure within a closed membrane hall can balance external loads of dead weight, wind, snow, etc. (air-supported structure).
It is important that the supporting air blower provided will ensure a permanent air supply and - coupled to a wind sensor and/or a snow warning system - can automatically increase the pressure for extreme weather conditions. In the event of a power failure, an emergency generating set and/or standby blower must be provided.

Of course, the supporting air blower can also be designed for air-conditioning functions (hot/cold air). From an economic point of view, the medium air is superior as a supporting structure, because conventional supporting structures - excepting the foundation - can be totally eliminated. Power and maintenance costs must be taken into account, however. The permanent pressure inside, which is sometimes felt unpleasant, is a disadvantage or air-supported structures.

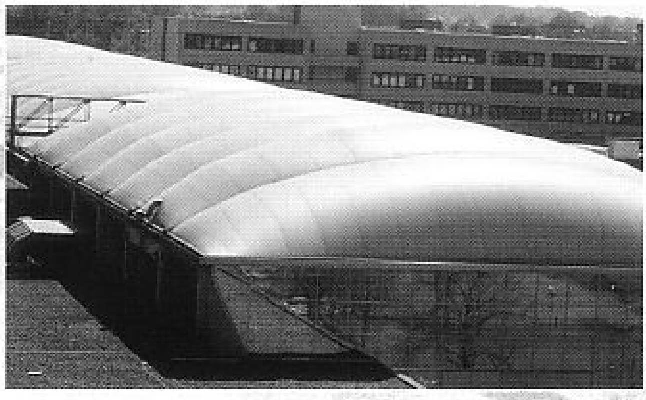


Tennis hall with double air-supported membrane for insulating function



Absorbers and collectors of textile membranes provide a heat benefit even in winter and thus become an environmentally beneficial power system

The use of pneumatic cushions, which can have separating functions, is an alternative. Although an additional supporting structure is required, it almost exclusively has to accept vertical loads, similar to conventional buildings.



Pneumatic cushions insulate and save

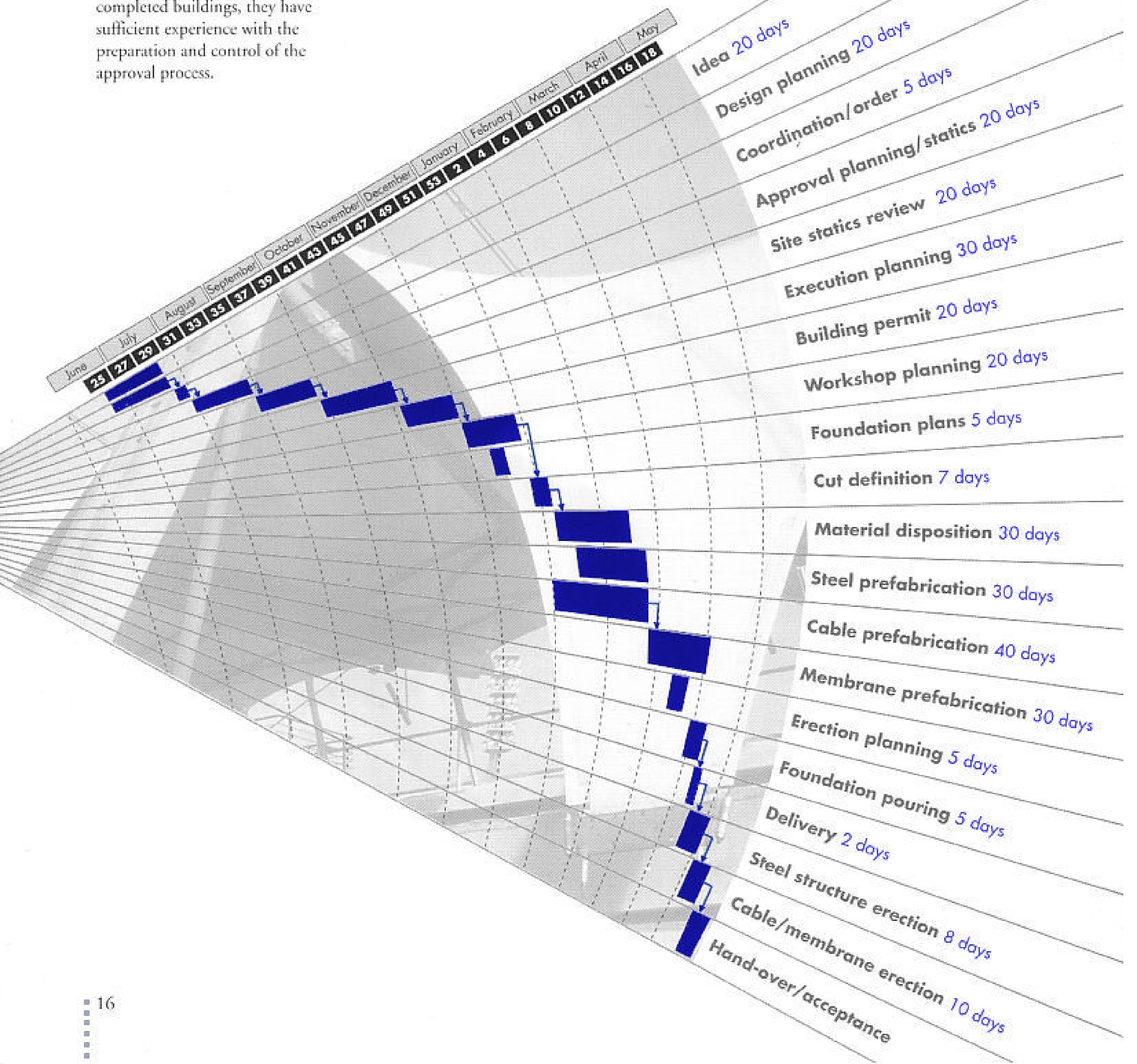
Manufacturing and erection

The time required from the first idea until erection is six to nine months, dependent on the project. Simple structures can be implemented faster, more complex designs, such as stadium roofing, may also take more than twelve to fifteen months. The planning phase, from the idea until approval planning, usually requires two to three months. The time required for approval frequently is hard to influence. Cooperation with experienced manufacturers pays again in this context, because, based on the great number of completed buildings, they have sufficient experience with the preparation and control of the approval process.

After the permit has been issued, another one to two months are needed for works planning, and then, dependent on the scope of the project, three to six months for manufacturing at the factory are needed. The erection on site is comparable to that of a prefabricated house.

The foundations are built on site parallel to manufacturing. About one to two weeks must be planned for the erection of an area of approx. 500 sqm.

Cutting of membrane runs



To return to planning: After the idea has become more concrete, the design planning starts, consisting of shape definition in conjunction with a rough static calculation. It is the objective of this service, which already involves considerable effort and is therefore invoiced, that a static equilibrium is worked out that is the basis for the most economic solution. This draft must then be coordinated with the functional and aesthetic site requirements. Final planning begins only then, and it ends with completion of the static calculations that can be reviewed. After the static calculation has been reviewed by a certified inspector, the execution plans are prepared, which are reviewed in turn. After final approval and release, the workshop drawings and cuts for the supporting structure, cables and membrane are prepared, and erection is planned.

Manufacturing a textile roof has some peculiar features. The supporting structure, for example of steel, can be differentiated from conventional steel support structures only in that minimum tolerances otherwise only known in machine building must be realized in part. This means: in certain areas, primarily where the connection geometry is involved, the metalworker assumes the functions of a precision mechanic.

Hihg-frequency welding units

Erection of the prefabricated membranes

Erection of large membrane elements

After definition of the final geometry, a cutting model is developed for the membrane by means of three-dimensional computer programs. This model reflects the planned preloading state under consideration of the elongation behavior of the chosen material. The individual resulting sections, including seam allowances, are transfered to the raw material supplied on reels, or they are cut out directly by means of special cutting computers. The resulting individual templets are then welded together under preload.

Checking of the finished membrane structure

The membranes are delivered to the site after the major part of the steel structure has been erected. Separate concepts are prepared for the erection sequence, partly including static erection state calculations regarding loads during individual erection phases.

Dependent on the project, erection takes only a few days or weeks, which is a great advantage for the site as such. All other work there can be performed almost without obstruction of any kind. Dependent on the local situation, it may be reasonable to erect the textile roofing at the very beginning.

Under certain conditions, this allows work to be continued under this roof, protected from weather, but it requires that precautions are taken to prevent destruction of or damage to the membrane or tensioning cables by construction vehicles or cranes. If the membrane is built only after completion of construction, it must be verified in advance that planned installations will not render this plan impossible. Erection after completion of construction is always recommended if a great amount of dust is generated, for example by excavation work, which would excessively soil the membrane which would then have to be cleaned.

After-Sales-Service

Maintenance agreement

Textile roofing is manufactured in such a manner that it is almost maintenance-free for its planned life. Retensioning, which was common practice at the beginning of this style in the early seventies, is no longer required with the materials and technologies used today.
The membrane itself does not corrode, as sheet steel does, for example, and it does not weather, like a wooden structure that needs to be painted at regular intervals.

Only the intended optical appearance should be checked at regular intervals - but this is the principal's decision.

Care and cleaning

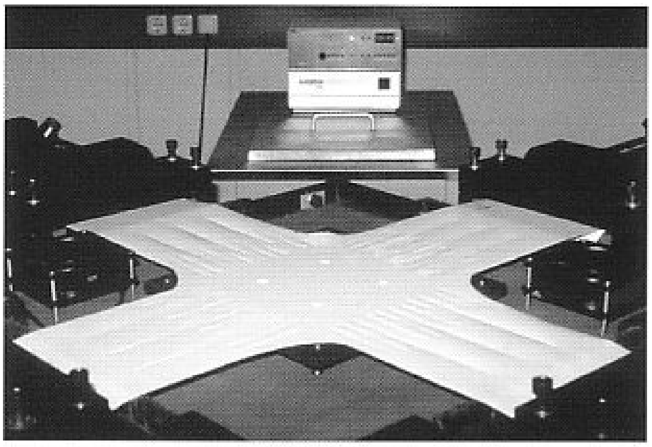
Just as the glass facade of a modern office building must be cleaned regularly, a textile roof should be cleaned from time to time. the modern surface protection paints used today (for example PVDF paint) or the glass/PTFE material are self-cleaning to a great extent due to the homogeneous surface. However, a patina, comparable to the soiling of a glass pane, naturally cannot be prevented.

Only the manufacturer should be contracted for cleaning, because the cleaning of membrane surfaces makes special requirements. In the interest of long life, a regular visual check of the membrane structure for damage due to external influences (storm, etc.) is also recommended.

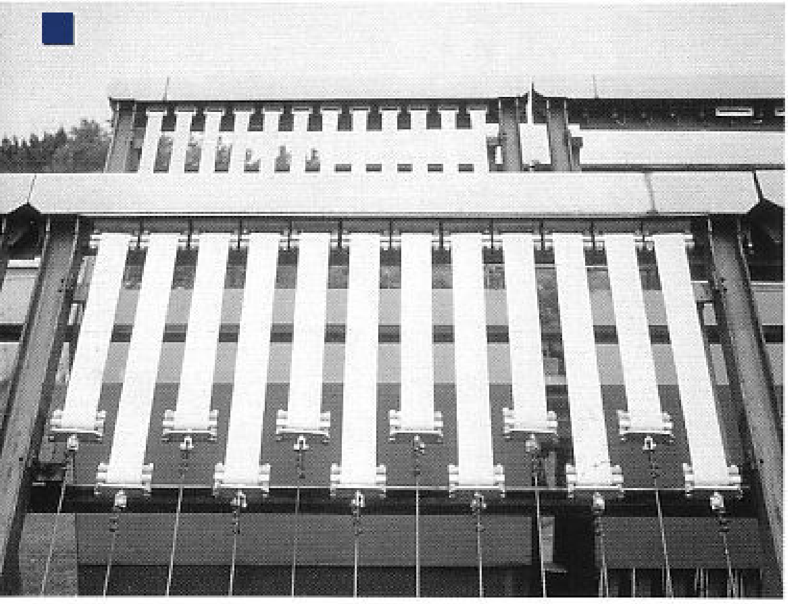
Material testing

The various material tests are performed according to the standards of the competent country. For example, along with maximum tensile force, maximum tensile force elongation, tear propagation tensile force values, adhesion values between the coating and fabric, chemical resistance and hard flammability are also tested for.

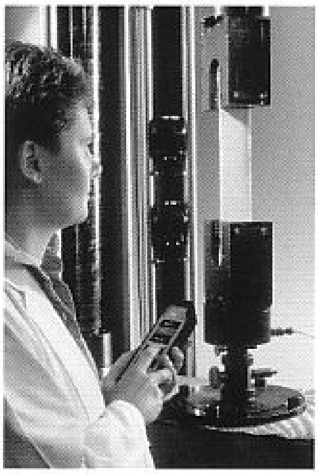
Dependent on the application and types of membranes, comprehensive examinations are necessary that require scientific and technically specialized labs and test facilities.



The biaxial test determines the force elongation behavior by cyclic loading in all directions



Today, exposed weathering is mandatory as a long-term test



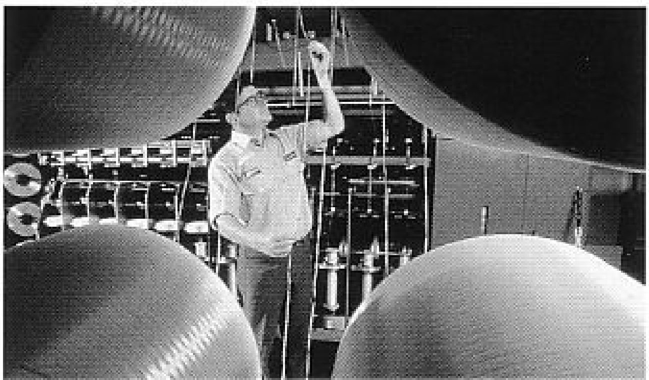
The values achieved for maximum tensile force elongation shows for most specimen that the specic strength of high tenacity chemical fibers is higher than that of conventional building steels.

Warranty

The young but established style 'textile building' has been established for more than 25 years in many thousand buildings worldwide. The minimum life expectancy of these structures, expert execution provided, is between 15 and 20 years dependent on the material. For glass/PTFE structures, even 25 years and more can be expected. Today, it is common practice that the warranty period of two or five years is granted, similar to conventional buildings.

Longer, phased warranty periods relative to the function are usually granted in conjunction with a maintenance agreement and must be taken into account in the price.

The fiber industry grants the quality warranty for high-tenacity filaments



Building permit

With respect to building laws, textile building is comparable to conventional building. Only temporary structures are an exception; they are subject to a special approval procedure. Analog to the specific requirements, static calculations must be prepared for textile buildings, where regional normal loads for wind and snow must be taken into account, as must special requirements like the building height or the intended use (e.g. requirements of the meeting facilities ordinance).

Requirements line the maximum building height, distances to neighbors and fire protection requirements also apply to the planned building location.
In addition to standard requirements, almost all European countries require special documentation relative to material, workmanship and safety, because the material 'coated fabric' is not yet included in the catalog of established building materials.

This documentation can be obtained without problems from renowned manufacturers of textile roofing. For the principal, these requirements are additional quality assurance measures. In some cases, the manufacturer already has approvals simplifying the approval procedure.

Route to building permit

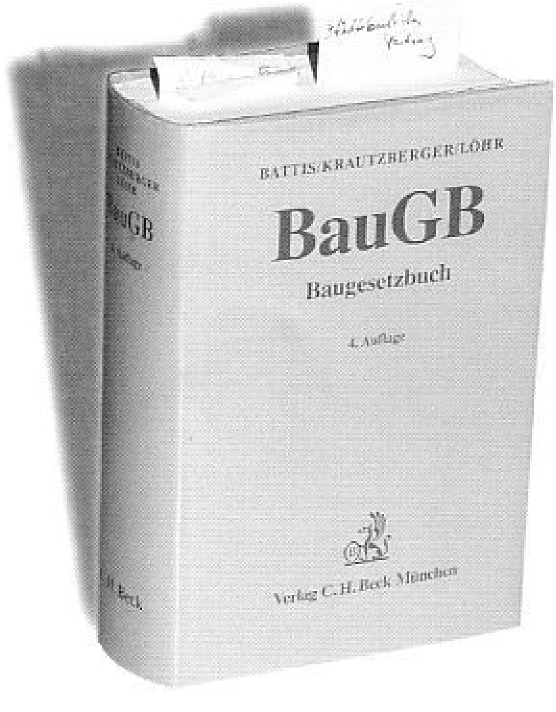
Before making the basic decision, discussion about the planned procedure with the competent building authority is reasonable. In this context, the planner will already receive comprehensive information about applicable regional conditions and possible requirements allowing goal-oriented planning.

After final clarification of all site requirements and completion of the design, the static calculations, which are capable of being reviewed, are prepared by the specialist engineer of the textile engineering company and provided to the site architect. He will then submit the application for a building permit. It is reasonable to try and convince the competent authority to involve a reviewer who is already experienced in this special method of construction.

During planning and design, preventive fire protection is an issue. If adequate distance to other buildings does not exist, requirements such as non-flammability (can be solved by using glass/PTFE material) or other measures can be made.
The textile building style offers an interesting possibility:
The smote/heat exhaust system usually required for conventional buildings is already integrated in a textile roof.
In case of a fire, the hard flammable material will open in the area of high heat (above the source of fire) and allow the smoke and heat to escape.

Various requirements apply to the temporary use of textile roofing in different countries. On the one hand - dependent on the planned duration of erection - they are to be viewed like a permanent building. However, under special circumstances certain reducing factors apply, for example for snow loads. Special requirements for dismountability are also made.

If regular re-erection is intended, so-called construction manual may be required that are reviewed by the competent local authority whenever the building is erected again.
If temporary use is intended, this should be taken into account already when planning is started.



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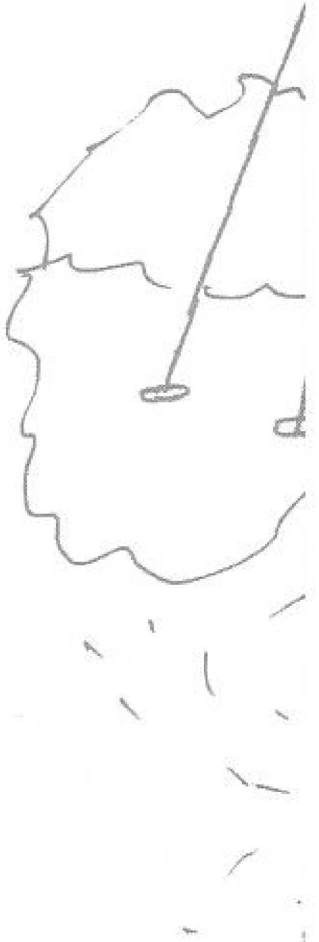

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