Tensioned fabrics

in art and architecture

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International Digital Laboratory

The University of Warwick

http://go.warwick.ac.uk/design21

THE UNIVERSITY OF WARWICK

Designing for the 21st Century

THE COURTAULD Institute of Art

Tensioned fabrics in art and architecture

From paintings of the past, present and future, to architectural enclosures – understanding fabrics in tension is the key to their conservation and design.

Fabrics shown in the exhibition are studied in two separate applications: as a medium for artists' paintings, and also as a material for sculpturing architectural enclosures (roofing forms). The linking factor is research methodology, involving the University of Warwick in novel computational strain analyses, and The Courtauld Institute of Art in the state-of-the-art measurement and evaluation of fabrics.

Design of fabrics for conservation of paintings and for sculptured enclosures requires good understanding of their response, in the form of strain and stress, to a variety of load cases and environmental conditions. Strain maps, obtained computationally and by direct measurement, give vivid pictorial representations of deformation patterns in the material. It is in these images that art meets engineering science.

Although paintings and sculptured fabric enclosures perform separate functions and convey different aesthetics, they both emerge from the study of Form. The question of Form has always challenged the art world, but, as this exhibition shows, it can also challenge engineers designing fabric structures for the 21st Century.

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Fabrics in architectural enclosures

Fabrics subjected to tension acquire new properties, such as stiffness, which makes them suitable materials for sculpturing architectural enclosures (roofing forms).

Tensioned fabrics are a popular feature in contemporary architecture, because they offer freedom of artistic expression and limitless exploitation potential, ranging from temporary or permanent event venues, roofs over sports stadia, to seasonal shades, and malls.

» Parque Expo'98 in Lisbon. Photograph courtesy of Canobbio S.P.A

« Walkway around the Millennium Dome

» 'Millennium Dome at dusk'. Photograph courtesy of QA Photos

Finding form...

Fabric enclosures are also known as 'free-form' structures. This means that their shape cannot be imposed, it has to be, quite literally, "found". The form-finding stage, which involves both computational and physical modelling, is the main feature that distinguishes a fabric enclosure from any other type of structure.

» *Soap film model*

An optimal membrane form is that of a soap film surface, also known as a **minimal form.** Soap **films** have some remarkable properties: they have uniform surface tension and a minimum surface area - they are very efficient structures. Although physical properties of architectural fabrics are quite different to those of soap films, sophisticated computational modelling, supported by sound conceptual design, allows us to get a good approximation to them.

» *Fabric models at a conceptual design stage*

The principle of constant surface tension and minimum surface area can be found in natural objects, such as trees. Tree growth ensures a **constant surface stress** on its trunk and branches. If a branch gets broken, the exposed area is 'healed' in such a way as to **minimise surface area.**

» *Exposed area healed after a branch has been lost*

Finding the optimal form of shell structures

A technique that employs flexible hanging models, such as fabric structures, can be used to determine optimal shapes of rigid structural forms, such as shells.

The shape is obtained by hanging a piece of fabric (or a series of chains), which, under their own gravity, develop pure tension. 'Freezing' this shape in a rigid material and then inverting it, will produce a structure working in compression - an optimum structural action for a shell.

This technique has been used by Antonio Gaudi (Spain) and Heinz Isler (Switzerland). The resulting full-scale structures are known to be strong, extremely durable, and aesthetically pleasing.

» Fabric hanging model prior to being 'frozen' in a rigid material

» Inverted rigid shape giving a shell structure

Conceptual design of fabric structures

Physical modelling is an essential part of conceptual design. As the images show, boundary configurations play a vital role in determining the shape of a fabric enclosure.

» Examples of boundaries determining the membrane form

Nature provides a good guide to efficient design. However, it is the art of engineering that turns naturally-inspired concepts into functional structures.

» 'Maple Leaf' canopy. A careful selection of low and high supporting points on the boundary of the fabric enclosure (red model) ensures adequate surface curvatures

» 'Flower' canopy. The fabric model has to be bound by rigid edges to achieve the intended shape and aesthetics

Architectural fabrics: applications

Most commonly used fabrics are:

Natural Canvas
suitable for temporary applications; tensile strength: ~35 kN/m; durability: ~ 5 years

» A shade in natural Canvas

PVC
(polyvinyl chloride) coated Polyester – three times as strong as canvas; durability: ~15 years

« Umbrella canopies in PVC-coated Polyester

PTFE
(polytetrafluorethylene), or Teflon-coated Glass Fibre – much less flexible than PVC/polyester; durability: ~ 50 years.

» The Dome in Teflon-coated Glass fibre

Fabric construction, properties and measurement

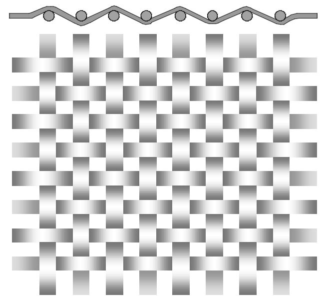
Fabric is a woven structure made from interlaced yarns. Simple weaves have one set of warp yarns running along the length of fabric, and one set of weft yarns at right angles to it.

Physical properties in warp, weft, and on the bias, vary. In order to predict the response of the material to loading, tests have to be carried out. The most reliable data is obtained from biaxial tensile tests. These are repeated for differing air temperatures, humidity, and state of dryness of the fabric.

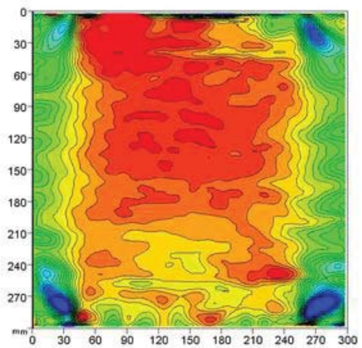
The Courtauld use an optical instrument called a 3D Electronic Speckle Pattern Interferometer (ESPI) to measure deformations of the fabric surface resulting from tensioning. It works by shining a laser light at the surface and recording, with a digital camera, a scattered light image. When the surface deforms, images are taken and compared with one another to determine the deformation. If the dimensions of the surface are known, a contour strain map can then be calculated and displayed.

Weft »

Warp »



» ESPI system



» Measured (weft) strain map

Computational strain modelling

The computational model developed at Warwick is based on a continuous (smooth) idealisation of the stress and strain fields in the fabric. It is the first model to include the combined effect of the folding and corner constraints, including friction forces, and staples.

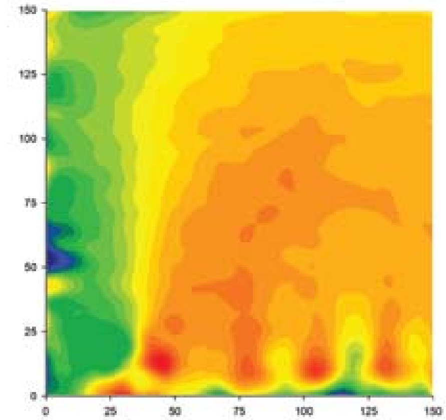
The canvas shown is stapled to the stretcher at regular intervals and then tensioned uniformly in both directions. The staples are placed on the sides of the stretcher.

The images of the two strain maps show the measured, and computed, weft strains developing in the fabric. Areas of highest strain concentration are shown in red; lower strain, in blue.

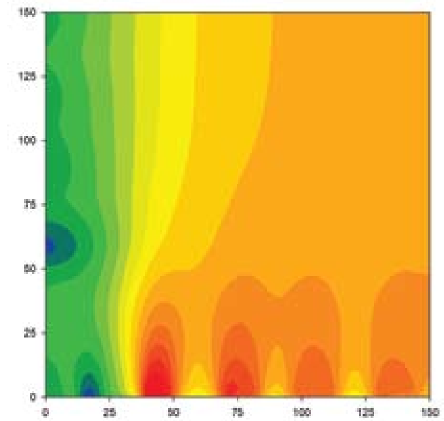
This innovative computer model of the behaviour of fabric can be used to improve upon the present methods of tensioning canvas.

» Corner fold and staple on the side of the bottom left-hand corner. (Staple aligned with the weft direction)

» Measured (weft) strain in the bottom left-hand corner of canvas



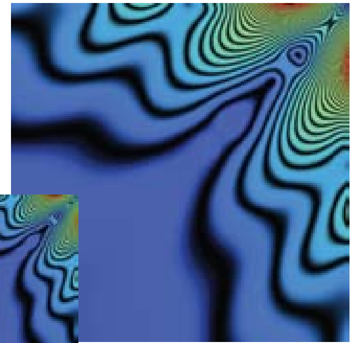
» Computer simulated (weft) strain in the bottom left-hand corner of canvas

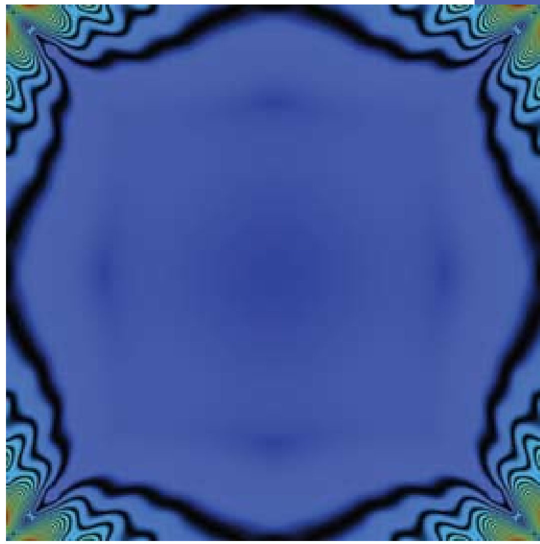


Simulating “stress at work”

Computer simulations allow us to examine different combinations of factors that are known to influence material behaviour.

The images included here illustrate the computer prediction of the distribution of strain in homogeneous materials, i.e., materials which, unlike fabric, exhibit the same physical properties in every direction.





« Pattern of stress in a sample of material stretched over a frame and uniformly tensioned

« Pattern of stress in a square plate subjected to tension in two directions and a slight shear force applied along the edges

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'Millennnium Dome at dusk'	QA PHOTOS, La Rosiere, 24620 Les Eyzies France. Qaphotos.com

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