CSEM's

Materials Monthly

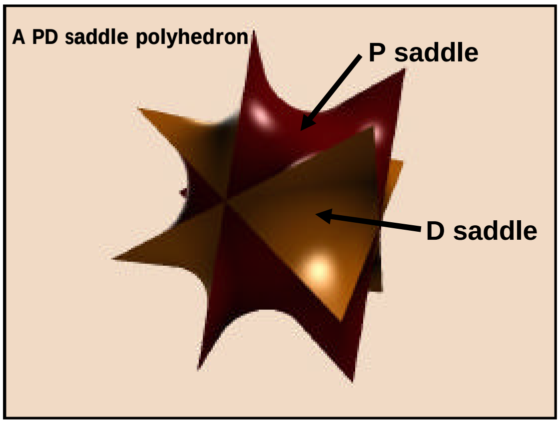
March 2003

Making materials matter

BUILDING THE BLOCK FANTASTIC

Saddle polyhedra could change the way we fill space

They look like chunky stars or simple sea urchins, but they're actually plastic representations of a revolutionary building block that's been modelled by scientists at Applied Maths and made 'real' by the rapid prototype machine at the School of Arts. Though maybe the adjective of 'revolutionary' should be replaced with the term 'evolutionary', because this star block combines features of some of Nature's most impressive designs.



Each block possesses 12 triangular spines with a bubble-like membrane stretched between them. Place a few of these 'star blocks' on a table and you get the impression there's no way they could neatly pack together. However, line up the faces of the star in different ways and incredible things happen. In one configuration they seamlessly pack together with no internal spaces at all. In another, they form an amazingly strong labyrinth where exactly half the structure is the blocks, and the other half is a void space in the form of highly regular channels.

The star block is a special three dimensional shape known as the PD saddle polyhedron. It was born out of theoretical geometry but it could have applications in understanding a wide variety of processes (such as molecular self assembly) and structures (such as a bee's honeycomb down to the closest packings of atoms in certain crystals). It's even possible that the star block could be the basis of a fantastic new building brick.

Birth of a block

The amazing block is the product of research by Applied Maths (RSPhysSE) on how space is partitioned in molecules and natural systems. For many years scientists in Applied Maths have been attempting to understand the structure of condensed matter at a range of different scales using a variety of techniques. One approach that has yielded important insights has been the work of Professor Stephen Hyde on understanding the role of curvature in condensed atomic and molecular materials. By applying differential geometry and topology to molecular frameworks it's possible to generate lattice-like mazes with continuous surfaces and no intersections. These maze structures help explain many of the properties of the material being examined.

Doctoral student Gerd Schroeder has been working with Stephen to breakdown the

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▲▲ Prof Stephen Hyde (left) and Gerd Schroeder demonstrate some of the amazing properties of the star blocks using plastic models produced in the rapid prototyper.

Inside this MM

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BUILDING THE BLOCK FANTASTIC

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continuous surface of some of these mazes into basic building blocks. One of these blocks is the PD saddle polyhedron. (The PD saddle polyhedron was first visualised by an architect named Peter Pearce in the 1970s. Applied Maths have created the same form using a different process.)

A polyhedron is simply a volume bounded by plane surfaces. A hexahedron, for example, is a space bounded by six planes. When those planes are the same size and all angles are perpendicular, the hexahedron is called a cube. A tetrahedron is bounded by four planes (a three sided pyramid). In a saddle polyhedron the planes that form the boundary of the volume are curved rather than flat in order to create a minimal surface. Think of it as a polyhedron made of wire dipped into a soap solution. The resulting soap film hanging between the wires will pull inwards to form a minimal surface as opposed to a flat plane. These curved surfaces are known as saddles.

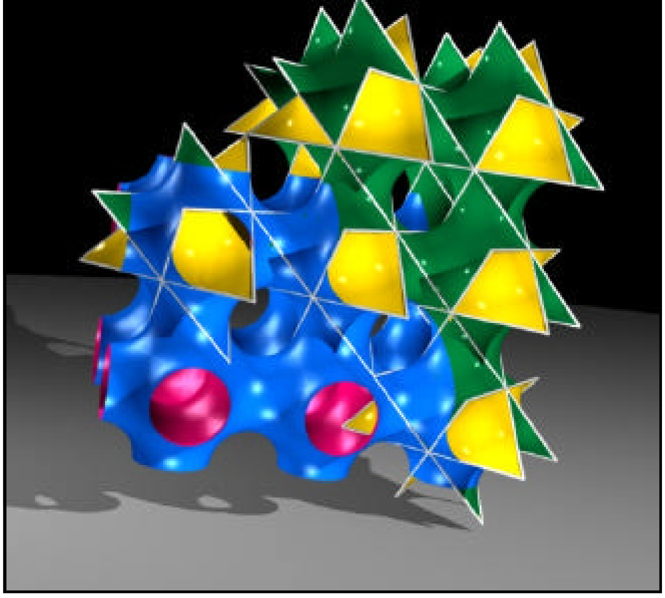
The PD saddle polyhedron consists of a mix of primitive (P) and diamond (D) saddles. The P saddle is the curved surface bounded by six edges. The D saddle is the curved surface bounded by four edges. The polyhedron consists of six diamond saddles and four primitive saddles.

Tiling space

It looks ungainly, but if you arrange several blocks such that the P saddles on one block are aligned to join the P saddles on a neighbouring block, and the D saddles join D saddles on the neighbouring block, you get a seamless match – a pile of tiles with no spaces between them at all. Of course, you can 'tile' three dimensional space with cubes and bricks but these polyhedrons don't lock together in the way that the star blocks do.

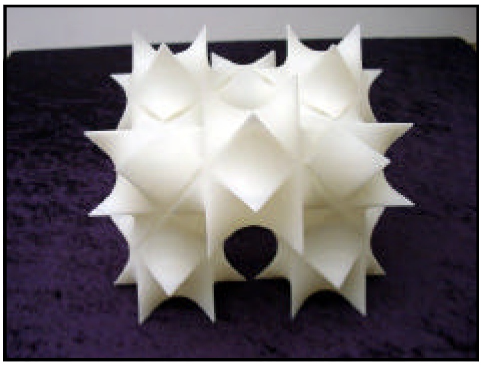
If you match up all the D saddles with D saddles on other blocks but don't match up P saddles to other P saddles you create a labyrinth in which the blocks makes up 50% of the volume and the void in between make up the other 50%. The labyrinth is a series of voids, each joined by six channels (referred to as a primitive or P spaces).

▼▼ Fig 1: A bi-continuous surface with star blocks.



▲▲ On first look, the star blocks don't look stackable.

And yet, match D saddle to D saddle and P saddle to P saddle and they form a seamless mass. ▼▼



You can visualise this in figure 1. At the top of the structure you can make out individual star blocks stacked together. Diamond saddles are yellow and primitive saddles are green. If you were to join up all the diamond saddles you'd form a P labyrinth. The lining of this labyrinth (the exterior surface of the blocks which is also all the primitive saddles that are left exposed) form the blue surface in the diagram. However, if you could visualise the inside of the star blocks, it would also form a P labyrinth of equal space (shown in the diagram as a pink surface). The P labyrinth, therefore, is actually a bi-continuous surface made up of the blue and pink surfaces.

In a similar manner, if you were to match up the P saddles on adjoining blocks (but don't join up the D saddles) you get another labyrinth, again 50% solid, 50% space, but this time each void is joined by four channels instead of six. This is referred to as a diamond or D space.

Clever curves

This is far more than just being a clever geometric puzzle as these shapes and surfaces are basic to the properties of many materials over a range of scales. The diamond labyrinth, for example, describes the arrangement of carbon atoms in the crystal lattice. It also describes how molecules of calcium carbonate lock together in the shell of a sea urchin. Possibly one of the most important applications of P

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Words of substance

"Geometry existed before the creation."
Plato

Materials Technology

FDM8000 Rapid Prototyper

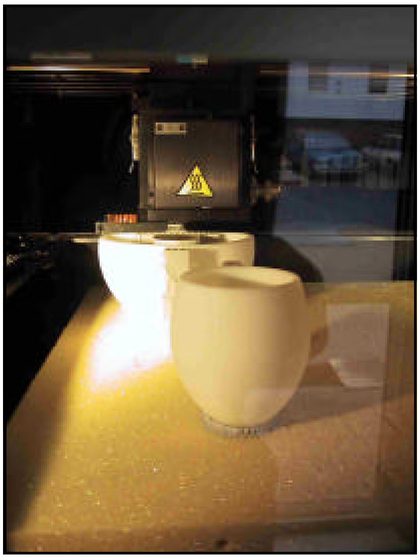
From the abstract into hard plastic

The Computer Art Studio, as part of the National Institute of the Arts, operates a rapid prototyping machine for producing three dimensional hard copies of computer generated designs. The machine is called the Stratasys FDM8000 (FDM stands for Fusion Deposition Modelling).

Once an object has been modelled/generated on CAD software the object is analysed and sliced into hundreds of thin layers (up to six layers per mm). These cross-sections are then layed down one by one in fast-setting, white, molten ABS plastic. Each layer fuses onto the layer underneath. As the layers build, the design takes form.

Where required, support structures are added in by the machine. These are laid down as brittle grey plastic, and serve as scaffolding to support the model as it grows. When the prototype is finished, the support plastic can be broken away leaving the model by itself.

The ABS plastic is a rigid and strong material. It can be sanded, painted, drilled and tested in a number of ways. There's even a 'medical grade' ABS for the creation of prototypes that can be used directly in clinical trials. Objects can be deigned so that other materials, like metal-strips, can be inserted during the build process, producing objects of composite material.



▲▲ An object being created within the FDM8000. Prototypes are constructed by building them up layer by layer.

With an upgrade, it's even possible for the rapid prototyper to create machine prototypes with moving parts. The process uses a system called 'waterworks' in which the plastic support structure is made of a water-soluble plastic. This is dissolved away when the model is complete allowing for the creation of working gears and moving parts to be created in one treatment – no assembly required.

Besides being used to produce hard copies of computer art, the facility has also been involved in a number of collaborations to generate prototypes of experimental components and designs. Examples includes the incredible PD saddle polyhedra (featured in this issue, see page 1) for Applied Maths, a model of a lens concentrator for the Centre for Sustainable Energy Systems and an extruder for the Department of Engineering.

For more information on the operation and use of the FDM8000, contact Gilbert Riedelbauch (Lecturer in Charge of the Computer Art Studio) on Gilbert.Riedelbauch@anu.edu.au

◀◀ Gilbert Riedelbauch, Head of the Computer Art Studio, holds one of the outputs from the rapid prototyper: a 'twisted sphere' (a hard copy of a complex geometrical form designed by Applied Maths).

◀◀ With an upgrade, the prototyper can even produce components with moving parts

▶▶ A prototype turbine created by the FDM8000.

▶▶ Computer art that would once have taken weeks or months to turn into 'real' objects can now be produced in hours. Pictured is Jeroen Bechtold, a visiting designer from the Netherlands with one of his designs turned real.

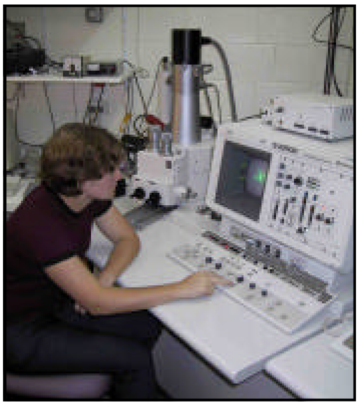
Opportunities

CSEM Prizes in 2003

Once again, CSEM is sponsoring two new prizes for students studying materials science and engineering in their Honours year. Each prize is worth $2,000 and will go to the student judged as having the best final year thesis. One award will go to the best thesis in the field of the 'Science of Materials'. The other will go to the thesis in the field of 'Application of Materials'.

The beauty of the awards is that they don't require the students to go to much additional work to enter. If you're enrolled in a program leading to the award of an undergraduate Bachelor degree at ANU and are submitting your final year Honours thesis this year, you're eligible. All you have to do is submit a copy of your thesis to the Director of CSEM by the 30 November.

More info: www.anu.edu.au/CSEM/Prizes.htm



◀◀ Christine Henry is a fourth year Science Law student. She's pictured here using the N-SEM (see story on page 5) to study the tip of an atomic force microscope that she's using in her studies of hydrodynamic forces between two approaching silica surfaces in aqueous surfactant solutions. While it's still early days, Christine should keep in mind she can enter her project in this years CSEM Prizes.

Nanoscience at the dome

Nanoscience: Where physics, chemistry and biology collide is the topic for the Australian Academy of Science's annual symposium to be held on **Friday, 2 May 2003** as part of *Science at the Shine Dome* in Canberra.

The program covers the biological, chemical, engineering and environmental aspects of nanoscience and features an impressive cast of speakers:

- **Dr Angela Belcher**, Massachusetts Instit of Tech
- **Dr Michael Barber**, CSIRO
- **Professor Frank Caruso**, Uni of Melbourne
- **Professor Paul McCormick**, Chief Executive Officer, Advanced Powder Technology
- **Dr Paul Mulvaney**, University of Melbourne
- **Dr Vijoleta Braach-Maksvytis**, CSIRO Nanotech
- **Professor Max Lu**, University of Queensland
- **Prof Bob Clark**, Centre for Quantum Computing
- **Dr Robin Batterham**, Chief Scientist, Commonwealth of Australia.

The symposium is open to scientists, media and the general community. The program and registration form are available on the web at **www.science.org.au/sats2003/index.htm**.

For further information contact Marian Heard at the Academy on phone 02 6247 5777 or email marian.heard@science.org.au

Diary: conferences and seminars

◀✧▶ Hannover Messe 2003 — **7-12 April**
8 trade shows in one: Factory automation, Microtechnology, Motion drive & automation, Energy, Compressed air & vacuum technology, Factory equipment & tools, Subcontracting, and Research & Technology
Hannover, Germany
http://www.hannovermesse.de/homepage_e

◀✧▶ Nanoscience: Where physics, chemistry and biology collide — **2 May**
Shine Science Dome, Acton (see above)
www.science.org.au/sats2003/index.htm

◀✧▶ Nanoengineering World Summit — **23-25 June**
Boston Massachusetts
http://www.iec.org/events/2003/nanoengineering/

◀✧▶ ICIAM 2003 — **7-11 July**
5th International Congress on Industrial and Applied Maths
Sydney
http://www.iciam.org/iciamHome/iciamHome_tf.html

◀✧▶ 3rd IEEE Nanotechnology Conference — **12-14 August**
San Francisco
http://ieeenano2003.arc.nasa.gov/index.html

◀✧▶ New materials and complexity — **2-9 November**
Canberra, ACT and Kioloa, south coast, NSW
http://wwwrsphysse.anu.edu.au/~col110/mat_complex.html

Materials Grab Bag

Nude SEM on the move

In the next few weeks the Electron Microscope Unit's smallest (but still very productive) scanning electron microscope, the Hitachi S2250 N (or NSEM), will be moved to RSES where it can be more easily accessed by its main users – the SHRIMP people who use it for cathodoluminescence to screen zircons.

The microscope (pictured on page 4) will still be a part of the ANUEMU, however PRISE and the Geochronology/Isotope Geochemistry Group will look after its routine operation. Other functions of the NSEM will migrate to the new JEOL 6460 which is the 'SEM' half of the FIB/SEM, due to arrive in a few weeks.

This machine is generally known as the 'N – SEM', because of its second trick, the ability to run with a small amount of gas around the specimen. This 'variable pressure', or 'extended pressure' operation means that uncoated, non-conductive specimens may be viewed without charging (or at any rate, without charging very much).

So where does the 'N' come from? Nobody seems really sure, and what follows may be an urban myth. The principle was worked out by Viv Robinson in Sydney – the Aussies called it a 'GeoSEM' and mainly used it for looking at rocks. The name of the Hitachi version may have started with the Japanese 'nama' meaning fresh, raw or unprocessed (as in draft beer). When the first US marketing campaign got underway, it was evidently supposed to be called a 'Nude-SEM', but as an adjustment to trans-Pacific cultural sensitivities, this was changed to 'Natural-SEM' (though this is a term I've never heard anybody actually use).

Sally Stowe
Facility Coordinator ANUEMU

BUILDING THE BLOCK FANTASTIC

(Continued from page 2)

and D shapes is an understanding of the mesophases formed in mixtures of oil-water-surfactants, where a (bi)layer of surfactant and oil separates into two water channels from each other.

Where this modelling might eventually lead, however, is as yet unknown though the applied mathematicians are confident it will be somewhere significant.

"Any nice mathematical object ends up being important," says Stephen. "It's the way the world works."

And history bears him out on this. Primitive and diamond surfaces were first visualised back in the 19th Century by the German mathematician Hermann Schwartz. He saw them as a curious type of minimal surface, his area of interest, but without any direct application. Only in the 1970s and 80s was their relevance to molecular self assembly in liquid crystals, phase transitions in crystals and to structures in zeolites discovered.

"What makes the star blocks so ripe with promise," says Gerd, "is that they combine properties of dense packing with the concept of minimal surfaces."

From dream to reality

"However, as an exercise in pure geometry, it's not easy for the uninitiated to visualise or manipulate the star blocks," says Gerd. "Consequently, we've looked for ways the three dimensional tiles could be rendered as real objects."

Converting the PD saddle polyhedron from a computer model into a real object has been made possible by a collaboration with Gilbert Riedelbauch at the ANU School of Arts. Gilbert operates a rapid prototype machine that can build three dimensional plastic objects from computer designs (see page 3 for details). He's built a range of fantastic shapes for the applied mathematicians over time, and these have proved invaluable in generating new insights on how the designs work or might be extended.

"The PD saddle polyhedra are amazing objects," says Gilbert. "However, it's not until you can physically hold them and lock them together in different configurations that their simple genius hits you."

Gerd now has a precious boxed set of eight star blocks. Each is around 10 cm in diameter. He takes them out whenever someone wants to see how these amazing shapes lock together. The block set is already catalysing new ideas.

And this is not the end of story. The star blocks are just the first product of breaking down poly-continuous surfaces into closed stackable cells. The mathematicians are already looking at how three or more intertwined mazes might be broken down.

"We've got mountains of potential blocks that could be worked up," says Stephen. "We see exciting potential for further collaborations with Gilbert at the School of Arts."

And the star block itself may be developed further. "Rapid prototyping has given us our first model," says Gerd. "Now it might be possible to use this prototype to cast the block in different materials such as glass or bronze. Who knows what we might then build."

For more information on PD saddle polyhedra, contact Gerd Schroeder (Gerd.Schroeder@rsphysse.anu.edu.au)

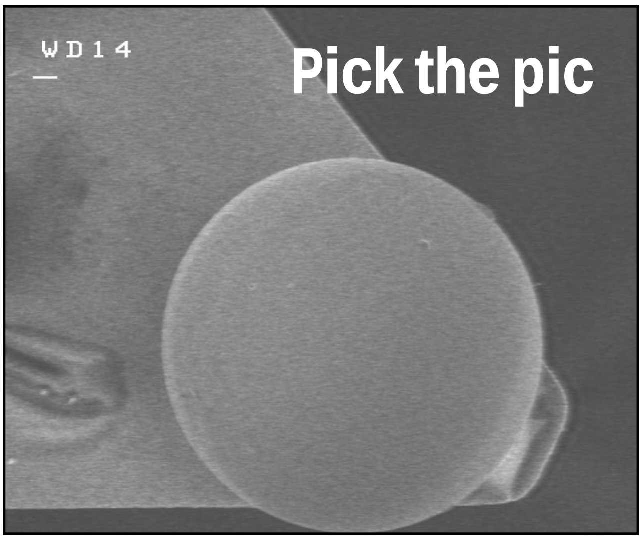

Stephen, Gerd and Gilbert building blocks.

the backpage

MM webspotting

Building **blocks** & geometry

- **Crystal Frameworks and Hyperbolic Tilings**
  http://anusf.anu.edu.au/Vizlab/viz_showcase/stephen_hyde/embed/
- **The Hyperbolic Toolbox**
  http://www.joma.org/vol2/articles/szydlik/szydtch.htm
- **Building blocks of matter**
  http://www.ewh.ieee.org/reg/7/millennium/neutrino/sno_indepth.html
- **Hyperbolic geometry**
  http://www.math.ubc.ca/~robles/hyperbolic/
- **Polyhedral Dissections**
  http://www.johnrausch.com/PuzzlingWorld/default.htm
- **Spacebricks for kids**
  http://www.spacebrick.com/



The ball pictured here is the silicon tip of an Atomic Force Microscope that will be used to measure hydrodynamic forces between two approaching silica surfaces in aqueous surfactant solutions (see p4, CSEM Prizes). The ball is approximately 20 micrometres in diameter.
Image taken by Christine Henry

CSEM

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Faculties
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Depart of Engineering (Faculty of Engineering and Information Technology)
Department of Geology (Faculty of Science)
Department of Physics (Faculty of Science)

National Institute of the Arts
Materials Workshops

AMTN is go!

Many CSEM members will be aware that ANU, through Professor Jim Williams (Director, RSPhysSE), has been championing the establishment of a new national research and technology network called the Australian Materials Technology Network (AMTN).

The AMTN aims to establish a broad-based network which will link all the major materials facilities, expertise and support organisations across the country to bring research and industry closer (and thereby enhance our manufacturing competitiveness).

The latest news is the Federal Government through its Innovation Access Program has given the AMTN the green light with funding to the tune of $2.6 million.

This major new development will be discussed in greater detail in coming issues of *Materials Monthly*.

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