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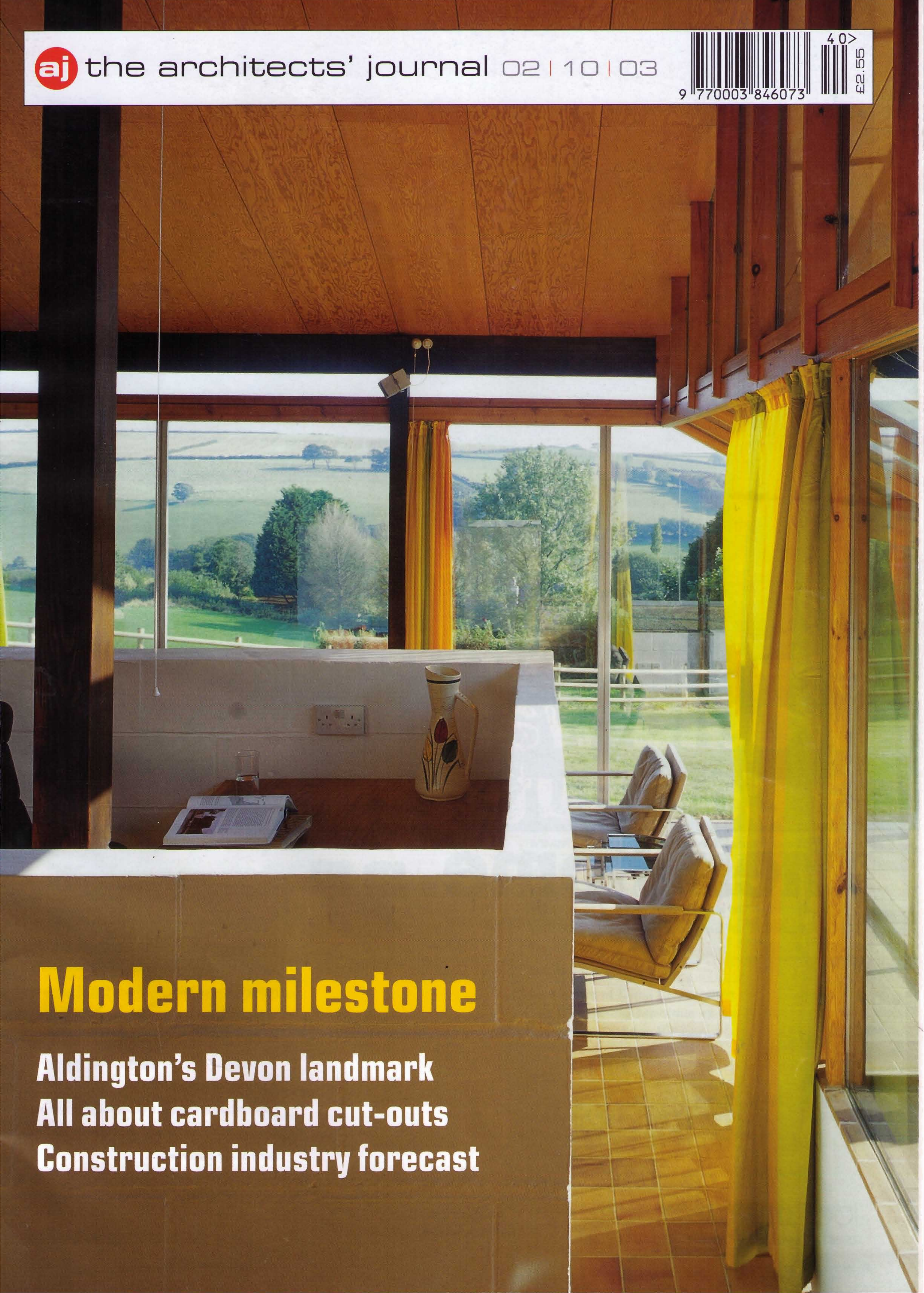

Modern milestone

Aldington's Devon landmark

All about cardboard cut-outs

Construction industry forecast

All a-board

Cardboard may be an unconventional structural material but to magma architecture it was totally appropriate

By Susan Dawson. Photographs by Magma Architecture

Even in these days of computer virtual reality, many architects still find that the best way to visualise a design is to take scalpel, cardboard and glue and construct a working model. So when magma architecture was asked to design an exhibition to display working models for the Building Centre Trust, the Berlin-based practice came up with an ingenious and totally appropriate solution: the exhibits are housed in a walk-through structure of cardboard, folded and glued together. It's a magical enclosure – just like walking through a life-sized model; it is also cheap, easy to erect and dismantle and demonstrates how cardboard can be used as a structural material.

The exhibition – titled 'Trial and Error' – was held on the ground floor entrance foyer of the Building Centre in London from 20 May to 2 August this year as part of a series commissioned by the Building Centre Trust to investigate 'the interface between the act of design and the fabrication of the built environment'. Its aim was to demonstrate the use of models as working tools, rather than as polished presentation pieces. So although some of the studies exhibited were never intended to be seen by those outside the project team, others were remarkably sleek and refined. Both physical three-dimensional objects and CAD images were exhibited from practices and designers including Studio Libeskind, Ocean North, Gehry & Partners, Richard Rogers Partnership and Thomas Heatherwick. Other exhibits, by Buro Happold, Arup Acoustics and Price & Myers, explored hypotheses tested in computer models and were used as verification of them.

magma architecture has designed the exhibition structure as an enclosed 'street' with well-defined entrance/exit points; the street forms a curve to negotiate several potentially difficult intrusions – columns, a pair of steps and a ramp. The folded cardboard walls have lights concealed behind them and their sloping shapes focus the light onto the models and images. 'We wanted it to be like a large sketch model that one can experience from within,' explains Martin Ostermann of magma architecture. 'And it is almost paper-thin; it captures the fragility and incompleteness of a true working model.'

Cardboard is cheap, flexible and readily available but its potential as a structural material has until recently been limited to a few projects. The Japanese architect Shigeru Ban has experimented with self-supporting walls constructed of large cardboard tubes (AR, September 1996) and his pavilion for Hannover Expo 2000 comprised a grid-shell of cardboard tubes, which acts as armature to wire-stiffened timber ladder-beams. In the UK, architect Cottrell & Vermeulen has designed an award-winning after-school club at Westborough School using an origami-shaped structure of cardboard panels.

Designing with cardboard

Florian Förster of Buro Happold describes the basic principles of cardboard structural design

As structural design with cardboard and paper products is not yet codified, the designer relies not only on empirical knowledge, project specific tests and the understanding of first principles of engineering but also on his willingness to take extra design responsibility. As a result, cardboard allows the designer to pursue structures that are not based on precedent and go beyond conventional building structures.

Cardboard and paper products are available in a variety of standard forms, mainly manufactured for the packaging industry. The following cardboard products are available.

Tubes – manufactured by rolling multiple layers of spirally wound paper plies over a spindle. The layers are glued together by starch or PVA. The tube wall thickness depends on the number of plies but can range up to 16mm. Tube diameters up to 600mm are commonly available.

Panels – manufactured by laminating sheets of paper or particles for solid boards. Honeycomb boards can be made by pressing paper pulp into a honeycomb mould and then sandwiching the honeycomb structure between sheets of paper: by gluing multiple sheets of paper together and pulling them apart or by gluing two halves of moulded honeycomb panels together. A number of L- and T-shaped and RHS sections are also available in cardboard.

Like other structural materials cardboard is best used in forms that exploit its inherent strength and material behaviour. Due to the manufacturing process cardboard is an anisotropic material, hence the material strength varies greatly depending on the direction of the stresses. It is most efficiently used to transfer axial and in-plane stresses only, a point which should be kept in mind when deciding the structural form and load path.

Columns – axially loaded columns can be designed from cardboard tubes. Load-bearing columns are generally of a large diameter and the ratio between the tube wall thickness and

Play your cards right: magma architecture has designed the exhibition structure as an enclosed 'street'. Lights are concealed behind the cardboard walls to focus on the models and images. It is intended to be 'like a large sketch model that one can experience from within'

For the two latter projects the structural engineer was Buro Happold; its expertise was further developed in another project – the construction of four large-scale cardboard building models, which formed the centrepiece of an exhibition in Japan to acknowledge the award of the Hiroshima Peace Prize to Daniel Libeskind in 2001. Ostermann – at that time part of the Libeskind practice – and structural engineer Florian Förster of Buro Happold worked together on the Peace Prize project. When the 'Trial and Error' exhibition was mooted it seemed logical that Förster and Ostermann – now in practice as magma architecture – should continue their cooperation. The result is a design (see Working Detail, pages 44-45) that explores the use of a new material in terms of its structure and stability, and the way it is fixed and jointed. As cardboard design has no precedents, it requires a deeper understanding of the principles involved; as this project demonstrates, it also offers the freedom to go beyond conventional ideas of form and construction.

CREDITS

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diameter is high. Hence tubes tend to fail locally in buckling. Overall buckling of the tubes is less likely due to the low slenderness ratio of the sections.

Beams – can be designed using sheets of honeycomb cardboard or sections. The support conditions of beams need to be considered carefully to avoid stress concentration and minimise shear deflection and shear creep. The use of tubes as beam elements is not recommended; their bending capacity is low as the outer surface layer is not continuous.

Walls – flat panels can be used for the design of walls, either load-bearing, self-supporting or mounted to a primary frame. In all cases the stiffness of the wall and its performance under lateral loads are critical. Stiffness can be enhanced by stiffeners, cross walls or by designing the wall as a folded plate. If the panels are mounted on a primary frame, the cardboard acts as a cladding material.

Buro Happold has established a number of tentative design parameters for cardboard. They are based on project-specific tests and particular products. As there are no general structural requirements and standards for cardboard products, the parameters need to be reassessed prior to each new project.

• Material properties of cardboard:
Cardboard tubes

Tensile/compressive strength	8.1 N/mm^2
Design tensile/compressive strength taking account of creep effects and a factor of safety (FOS) of 10:	0.8 N/mm^2
E-value:	1,000-1,500 N/mm^2

20mm-thick honeycomb sheets

Bending strength:	6.9 N/mm^2
Design tensile/ compressive strength taking account of creep effects and a FOS of 10:	0.6 N/mm^2
E-value:	1,000 N/mm^2

All values relate to a stress direction parallel to the surface. Stresses perpendicular to the surface have not been tested.

An exhibition structure made of cardboard

The exhibition structure is composed of five layers of cardboard panels, stacked to form walls, which loosely follow the outline of the exhibition space. The panels change in height and fold in different directions to the ones above and below; they are all flat but not generally vertical. The folded arrangement creates steps and 'shelves' on which the designers' models are positioned.

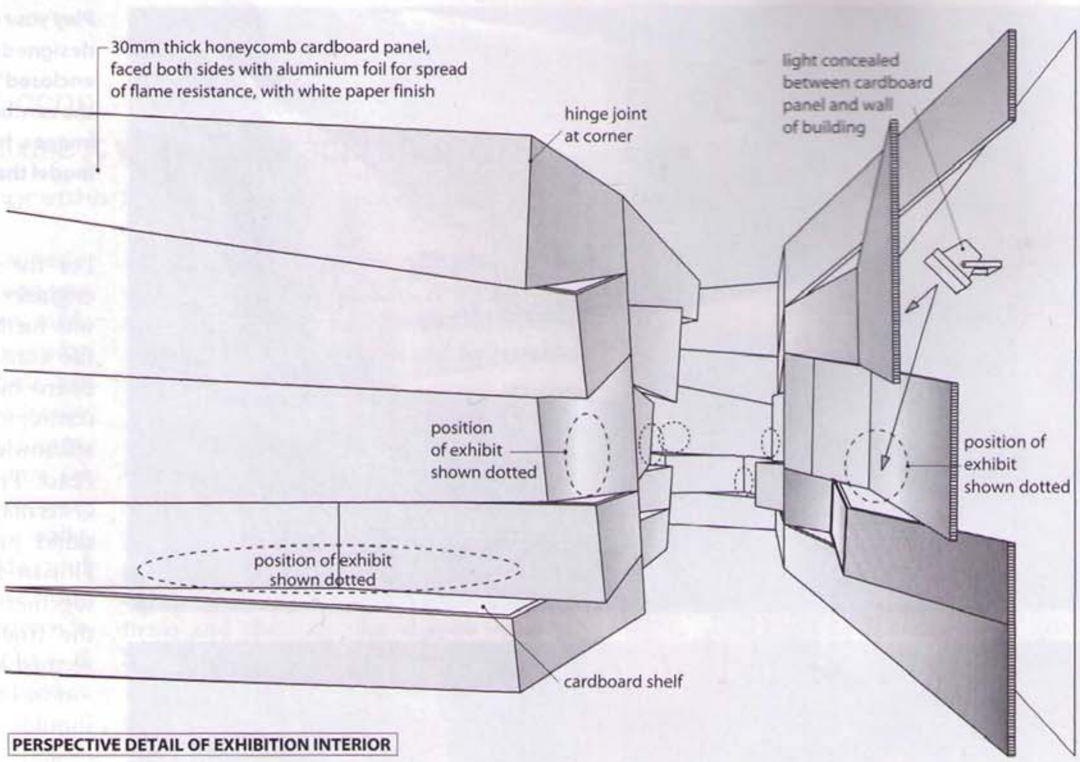
The overall stability of the structure is achieved by the folding geometry of the walls and by overlapping the panels, so that, for example, the folded portion of an upper panel is triangulated with the straight portion of the panel below it and vice versa.

The panels are of 30mm-thick honeycomb cardboard, faced both sides with aluminium foil to give resistance to spread of flame; they have a thin white paper finish. The panels are structural. The top edges of the upper panels are hung from an existing ceiling track with a ring and hook connection; the bottom panels are held in position by screw-fixing them to the ground-floor slab.

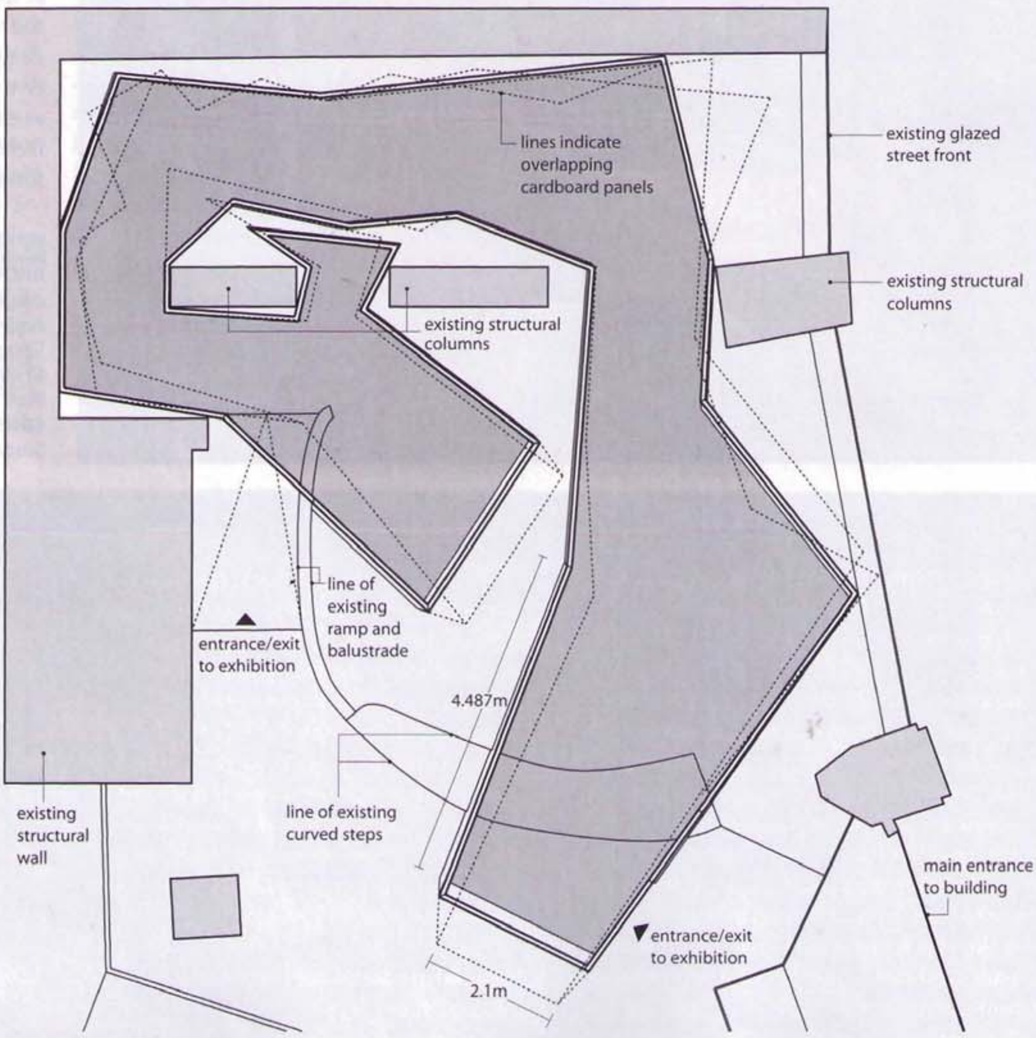
Folds at panel junctions are made with 50mm-wide brass hinges screw-fixed to panel-edge battens; the joint is reinforced with white card angles, which were glue-fixed on site, giving rigidity to each layer of panels.

The design was developed by means of a computer modelling tool, which dimensioned and defined the angles of all the cardboard panels; they were then pre-cut to the correct shapes and delivered to site as flat panels. Once on site the lower band of folding wall panels and all full-height panels were installed and supported from the ceiling. For stiffening, a 50 x 29mm softwood batten was glue-fixed to the top edge of a panel on which an upper band of panels would rest.

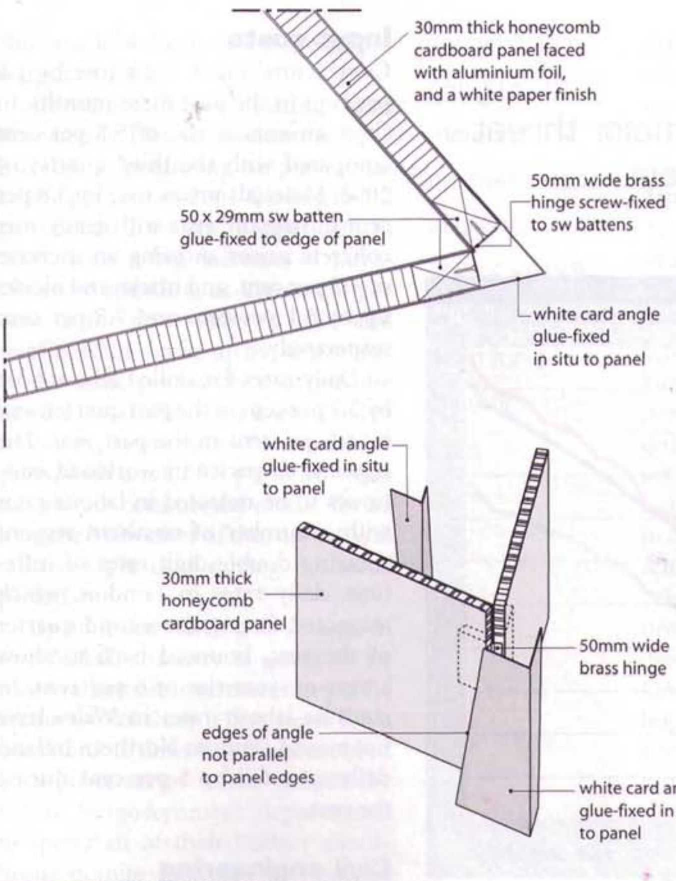
Susan Dawson



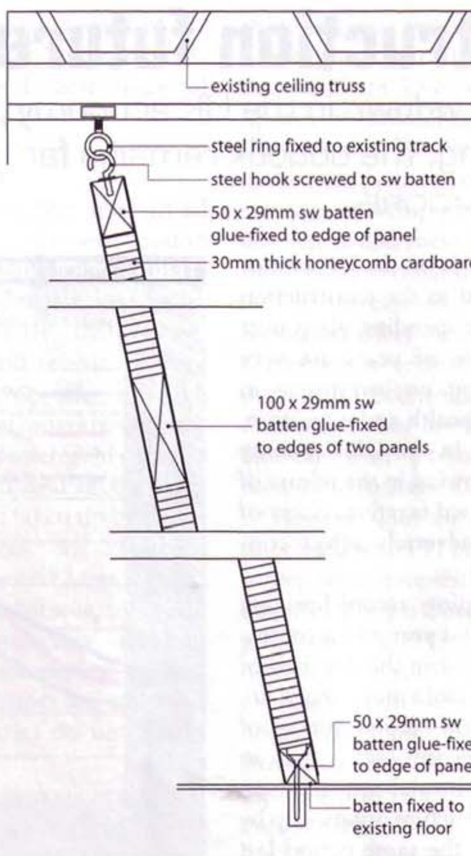
PERSPECTIVE DETAIL OF EXHIBITION INTERIOR



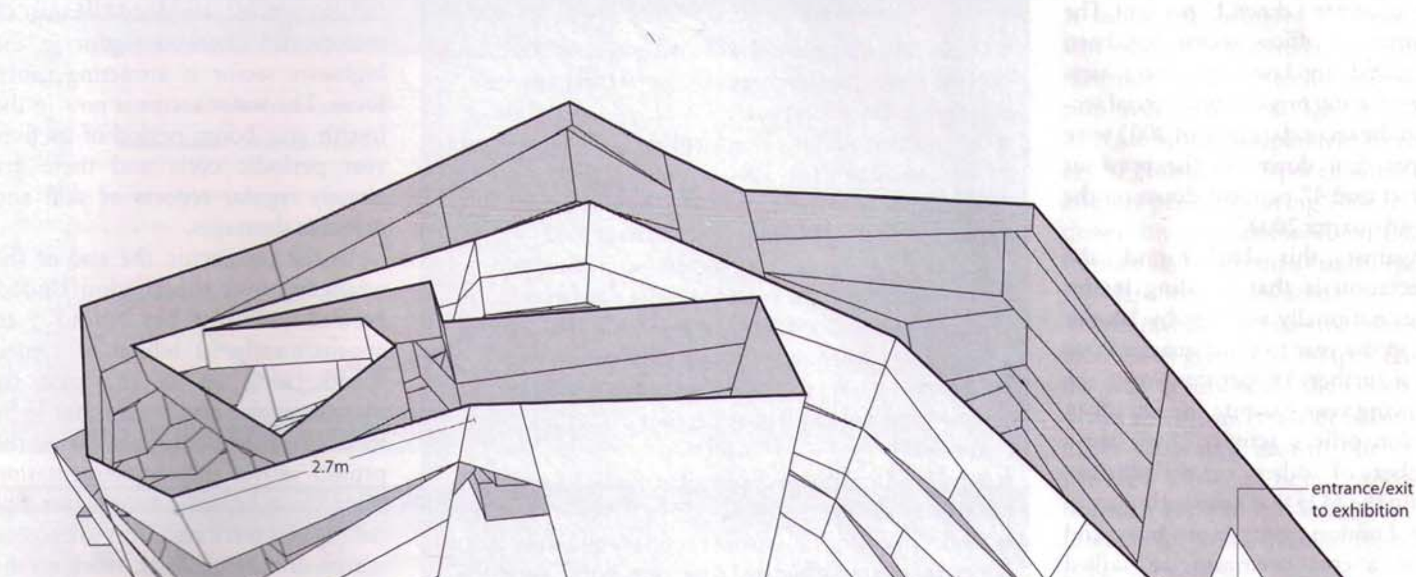
PLAN OF EXHIBITION LAYOUT



PLAN AND ISOMETRIC SKETCH AT CORNER



DETAIL SECTION THROUGH CARDBOARD WALL



PERSPECTIVE SKETCH OF EXHIBITION LAYOUT