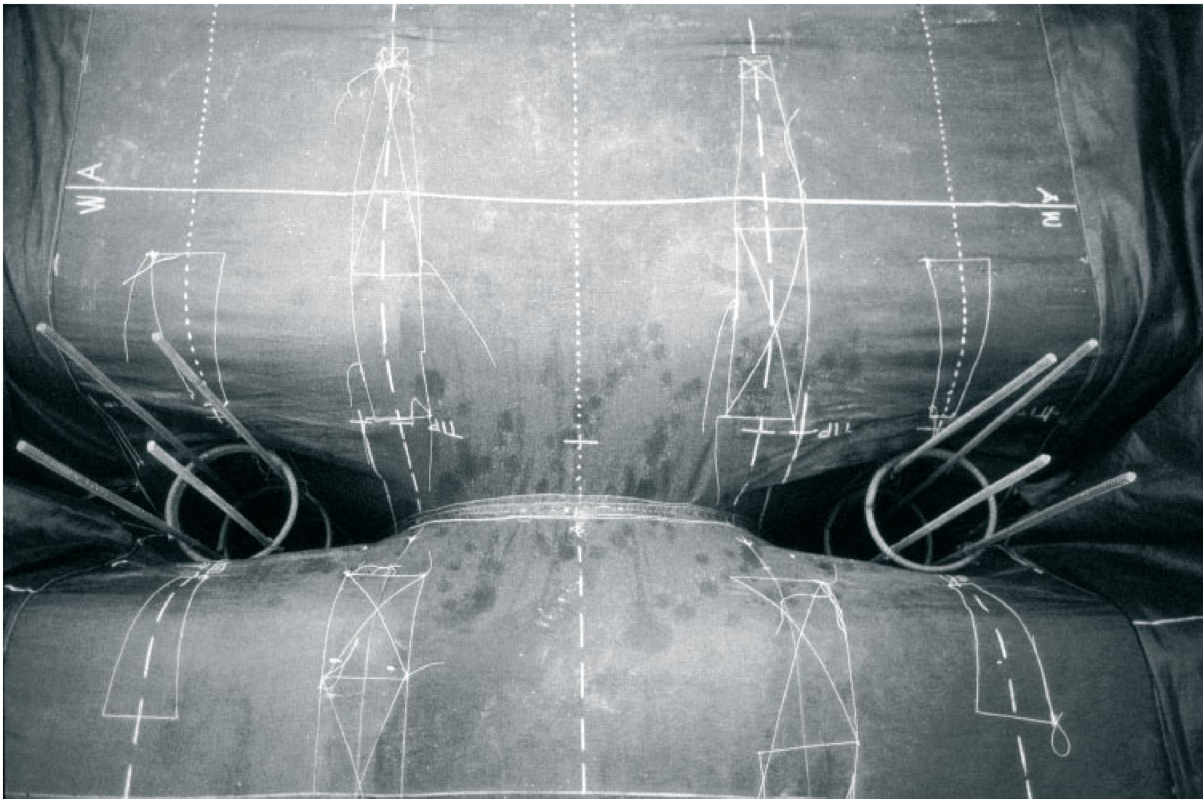
Thinking

with Matter

Mark West considers the qualities of the analogue against the digital in the context of his work at the Centre for Architectural Structures and Technology (CAST) at Manitoba. Unable to fault the computer's ability to provide complex calculations for the fabrication of forms, he insists that the fidelity and investigative potential that he has found in the reality of the physical model and hand-drafted drawing have yet to be surpassed.

Plaster test model for sprayed-concrete thin-shell panel, 2007
Detail of a spray-plaster, thin-shell analogue model used to develop the 2.4-metre (7.9-foot) tall thin-shell wall panel. This photograph shows a small portion of a 65-centimetre (25.6-inch) tall, 5-millimetre (0.2-inch) thick plaster model.



Slab to column form detail, 1992
A view looking down on an early experimental formwork design for a cast-in-place, one-way structural slab. Two flat sheets of geotextile fabric, supported from below on shoring beams, are joined to each other to produce a mould to form a pair of columns, a transverse 'beam drop' and a ribbed slab. Only the column reinforcing is shown here.

Research at the Centre for Architectural Structures and Technology (CAST) at the University of Manitoba in Canada is grounded in physical analogues. CAST researchers think through drawings made of powder (graphite, chalk) and physical models contrived to function as much like their full-scale counterparts as possible. 'Model' is always both noun and verb.

The constructions produced are essentially 'method prototypes' rather than miniature objects (though they serve this function as well), and these analogue models have proven themselves to be very reliable. Over 18 years of research it has been found that if something is buildable in CAST's analogue models, it will be buildable at full scale. The fidelity of the models is due to the analogous nature of the materials used (plaster to model concrete, light fabrics to model industrial geotextiles, and so on), and to the fact that tension forces scale linearly, making mechanical comparisons directly proportional for the most part, and highly intuitive.

Historical precedents for this way of working include, for example, Gaudí's hanging model of the Colonia Güell Chapel near Barcelona, the soap films of Frei Otto, and the hanging fabric shell models of Heinz Isler. In each case their forms were generated in the realm of linear tension, allowing complex full-scale geometries and constructions to be modelled and developed without the need for computers. Now, of course, we have access to computer-modelling software, which was unavailable to the early great explorers in this realm. We are faced with a conscious choice to think and work through physical analogues.

A physical model (as verb) is excellent because, bound as it is in actual reality (AR), it is qualitatively rich: full of dense information about physical forces and strains, construction sequence and detail. It is very difficult, however, to get quantitative information out of this kind of model.[1] Digital models, on the other hand, are excellent because they are rich in quantity: indeed, they are composed of quantities, and this content makes them invaluable in any building culture that must calculate before constructing. Calculations for structures composed of planar surfaces and uniform section volumes are simple enough to be carried out manually. Structures composed

Beam model formwork, 2003
A 1.5-metre (4.9-foot) model formwork used to work out the construction method for a 12-metre (39.4-foot). reinforced-concrete beam with double cantilevers. This mould, made from a light 'rip-stop' nylon fabric, was filled with plaster. Both the model and the full-scale reinforced-concrete beam are formed in a single flat sheet of fabric stretched into the gap between two plywood 'tables'.

Full-scale fabric formwork beam cast, 2003
Full-scale, 12-metre (39.4-foot) fabric beam formwork filled with concrete. This is the full-scale equivalent of the 1.5-metre (4.9-foot) analogue formwork. The black fabric mould is a flat rectangle of inexpensive geotextile fabric.

of complex curves, such as those generated by tension or compression surfaces and flexible moulds, are more difficult to quantify and predict. Behold the sad scene of the architect who cannot calculate what can be built. For this we need digital models. Indeed, CAST is actively searching for partners who can help in digitising the forms it has found physically.

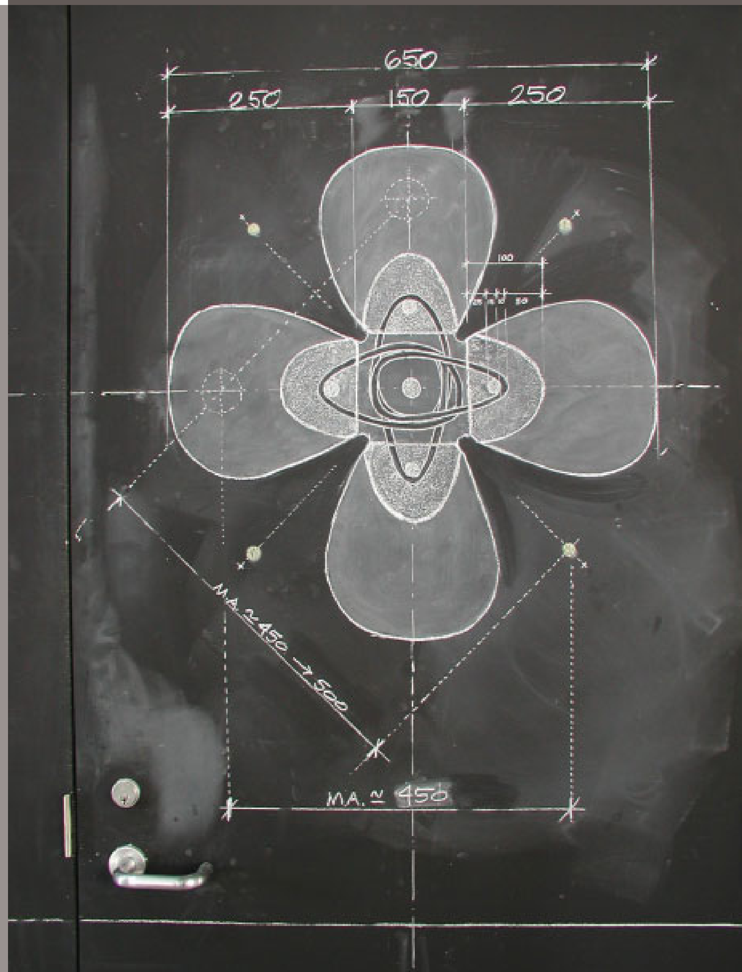
Some digital models are essentially equivalent to their physical counterparts. For example, relatively small milled objects or objects produced from milled moulds can be the end product of a seamless line from digital model to industrial computer numerically controlled (CNC) production. But for larger things cast from assembled moulds (such as buildings), this line is broken by the necessity for handwork. Digitally generated architectural form, rich as it may be in quantity and calculation, remains in this sense disconnected from the world of

Branching column model test, 2007
Close-up detail of a plaster model for a fabric-formed branching column, showing about 6 centimetres (2.4 inches) of a 31-centimetre (12.2-inch) high model used to design the formwork for a 10-metre (32.8-foot) full-scale prototype column.

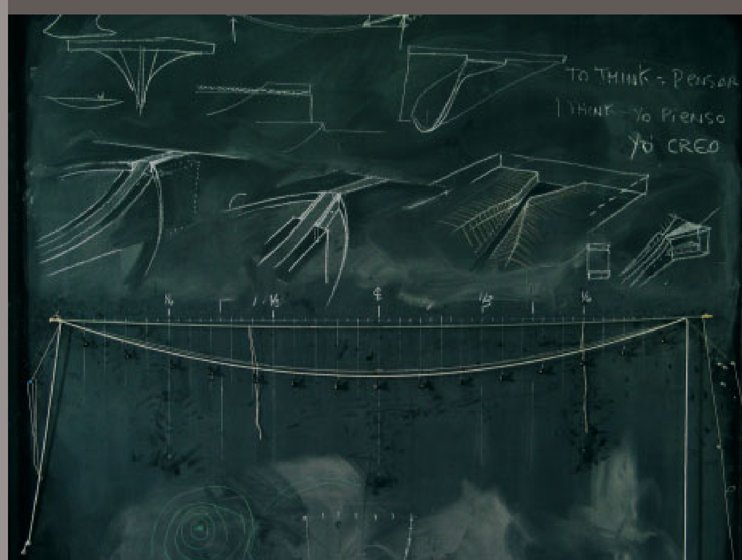
Full-scale branching column formwork, 2007
Composite photograph of branching column formworks filled with concrete. This method uses modified standard plywood wall-formwork, with geotextile fabric form-liners, to cast fabric-formed columns (or, alternatively, concrete walls with fabric-formed pilasters).

12-metre fabric-cast beam, 2003
A 12-metre (39.4-foot) double-cantilever, reinforced-concrete beam cast in a single flat sheet of fabric. A flexible fabric mould vastly simplifies the formation of beams that follow their bending moment curves. This produces beautiful structures that significantly reduce dead weight and materials consumed in construction.

Chalk wall drawings/beam end studies, 2004
The walls of the CAST laboratory are painted with chalkboard paint, giving us large surfaces on which to draw out our ideas. The chalk drawings shown here explore possible constructions and configurations for the ends (support condition) of variable-section, fabric-formed T-beams. Below these drawings is our device for drawing bending moment curves and the placement of reinforcing steel (a hanging string and a simple spline).



Chalk wall drawing/1:1 column plan detail study, 2003
Full-scale plan-section drawing through a composite (four-part) reinforced-concrete, fabric-formed column design for La Ciudad Abierta (the Open City) in Ritoque, Chile. Full-scale chalk drawings such as this allow us to work out the placement of reinforcing steel final construction dimensions.



Reinforced-concrete bollard detail, 1995
Like all of CAST's work, this bollard is formed in moulds made from flat rectangles of fabric: no tailoring for curvatures, just flat sheets directly off the roll. In this case the mould was a sheet of Lycra spandex. A stretch-resistant outer jacket was used to partially control the deflection of the spandex.

physical construction by virtue of its size. By and large, complex digitally generated forms are extremely difficult to get out of the computer and into the physical world. Behold the sorry scene of the architect with the digitally generated blob begging the builder and the engineer to figure out how to construct the marvellous design. Economy usually dictates that these ambitious designs will tend to devolve towards simpler, conventional forms. If the money and will exists to actually build some difficult new form (an investment in the 'wow effect', perhaps), then here is the sorry scene of resources and capital squandered in the difficult task of physically constructing something whose origin has no physically constructed reference.

Based on these considerations, physical model prototypes are by far the best way to find and develop new, buildable architectural forms. The speed and awesome resolution of AR allows us to think, imagine and discover quickly in an inexpensive, non-punitive environment. Naturally, the relative quality and shortcomings of the analogues will determine how far towards full-scale construction knowledge these models take us. Nevertheless, their greatest virtue remains that no matter what kind of form we find, we already know how to build it because the form was found by building.

Form research at CAST embraces both sculptural and structural forms. The search for sculptural form does not begin with a design, but rather with a choice of materials and methods. Here the forms that are found are given rather than 'designed', as the materials themselves dictate their final disposition in space through the urgencies of natural law. The search for structural form, on the other hand, is more directed in the attempt to follow specific, efficient and calculable force 'paths' through matter. Although certain aspects of these structural forms are decided upon by the materials themselves, the overall structural geometry is known before making begins.

Looking for construction methods to form efficiently shaped structures is like attempting to hit the centre of a pre-existing target with a rifle. The search for sculptural form, however, is more like shooting a shotgun against a wall and drawing bull's-eyes around all the holes.[2] The 'shotgun' approach is CAST's basic research, to learn what is possible without preimposing artificial limitations. In this the researchers work like artists. The 'rifle' approach is the applied research where techniques selected from all the interesting shotgun holes are used to construct some specific instrumental thing.

CAST's research is specifically architectural in that it simultaneously partakes of the narrow scientific traditions of engineering and the techniques of open discovery proper to the 'fine' arts. The evaluation of what is found is determined by its efficacy (practical, economical, sustainable) and by its beauty (as felt). When simplicity of construction, economy of material consumption and a kind of effortless beauty and evocation coincide, we know we are on the right track. Any ambition towards this kind of simple complexity requires the assistance of Matter (who always knows best). AD

This work is supported by the Social Science and Humanities Research Council of Canada (SSHRC) and the Lafarge Construction Materials Group, Winnipeg, Canada. Special thanks to CAST's Team Gravity: graduate research assistants Chris Wiebe, Phil Christenson, Aynslee Hurdal, Leif Friggstad, Mike Johnson, Kyle Martens and Tom Alston, and engineer and PhD candidate Fariborz Hashemian.

Notes

1. This difficulty is attested to by the fact that Gaudí only used his hanging model once, reverting afterwards to standard graphic statics calculations. Heinz Isler was able to obtain quantitative information from his physical models only through painstaking and super-precise handwork, a task so delicate that he refused to let anyone else perform this work and could not be interrupted without causing disruptions in the consistency of the data. As described in John Chilton's *Heinz Isler: The Engineer's Contribution to Contemporary Architecture*, Thomas Telford (London), 2000.
2. I take the 'shotgun' image of research from Steven Vogel's *Life in Moving Fluids: The Physical Life of Flow*, Princeton University Press (Princeton, NJ), 1981, p 3.