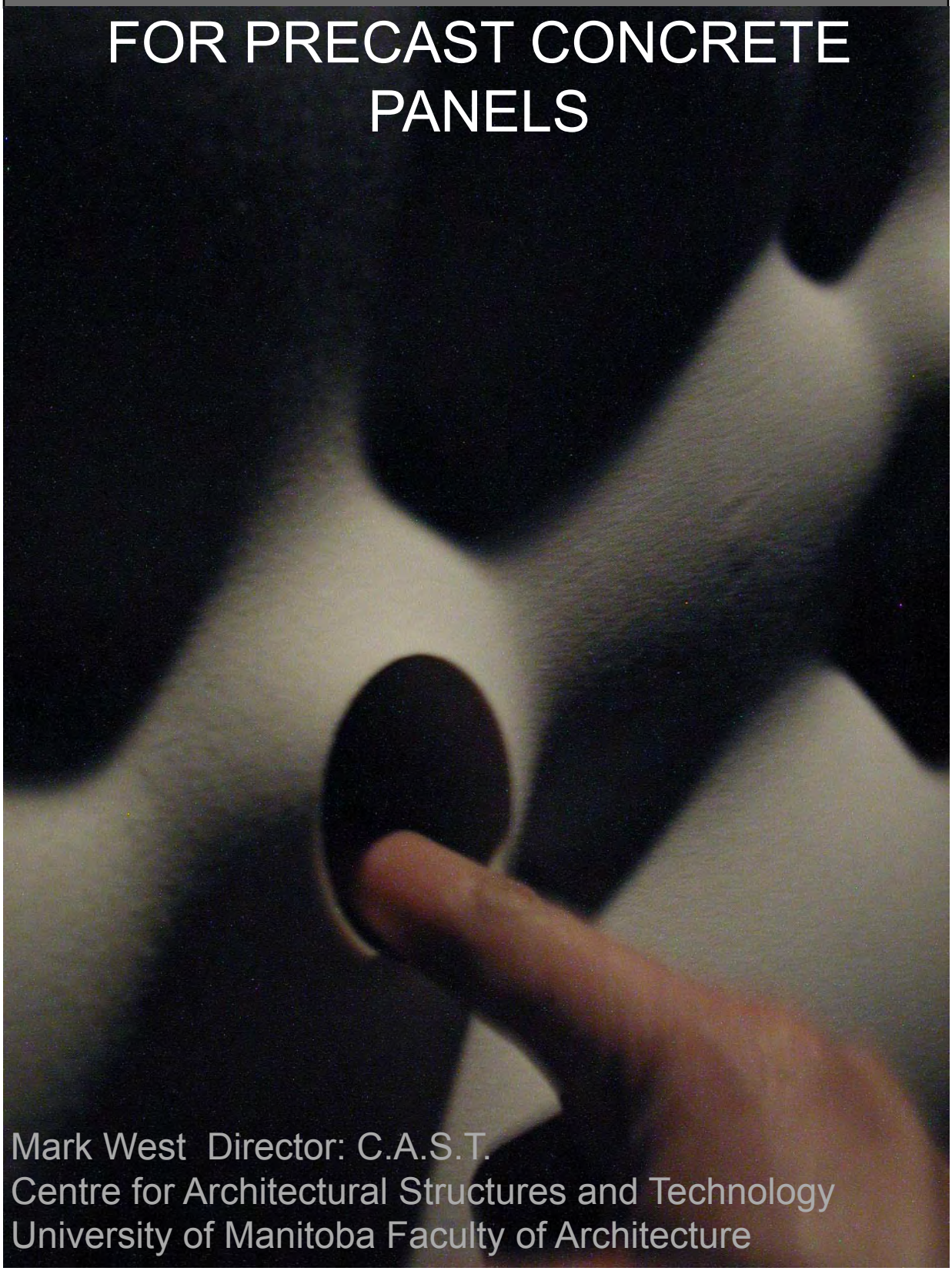
PRESTRESSED FABRIC FORMWORKS FOR PRECAST CONCRETE PANELS



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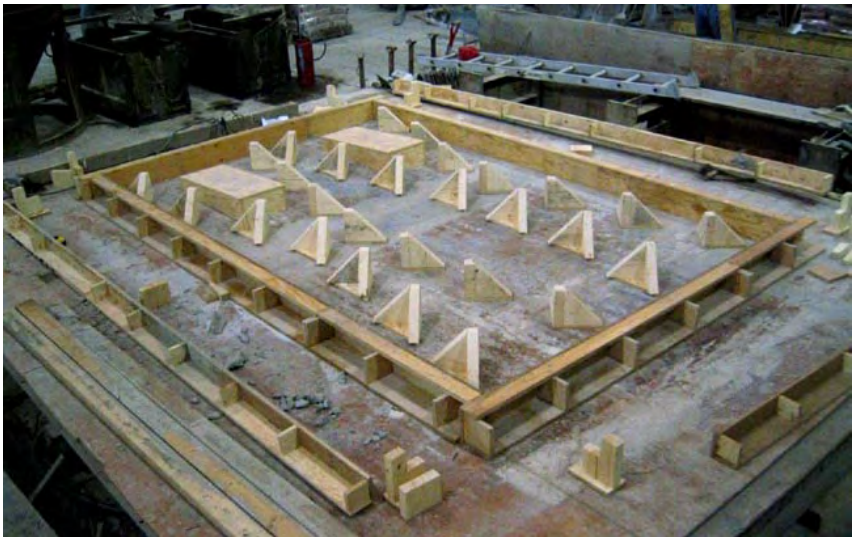

Figure 1. Lower frame with intermediate supports in place prior to place

Figure 2. Steel pre-tensioning frame with fabric attached

Figure 3 (below). Complete formwork prior to placement of concrete: The fabric formwork membrane has been pre-tensioned over the lower frame and intermediate supports, and the upper frame and reinforcing is in place above the fabric membrane.

CASTING CONCRETE PANELS IN FLEXIBLE FABRIC MOLDS:

A new class of precast concrete panels can be constructed using a mildly prestressed fabric sheet as formwork. Unlike conventional formwork technology, which relies on rigid and typically prismatic containers, fabric formworks are flexible, and are allowed to deflect under the weight of the concrete they contain. As a result, these casts are defined by three-dimensional tension curves rather than planar surfaces. The geometry of the formworks' deflections will vary depending on the weight and distribution of the concrete, the elasticity and prestress levels of the fabric membrane, and the boundary and intermediate support conditions provided. The geometric design of these panels is achieved by altering these constraints. The panels described in this article are 2.4 m by 3.7 m (8 ft. by 12 ft.). Two basic types of panels, "Direct Cast" and "Inverted Shell" panels are described as follows:

"Direct-Cast" Panels: A Lower Frame, which matches the final dimensions of the panel to be formed, is prepared with intermediate supports placed inside it. **Figure 1** shows a lower frame with intermediate supports. A fabric membrane is held and pre-tensioned over this frame and intermediate supports using a pretensioning frame. **Figure 2** shows a steel pretensioning frame. Placed above the fabric sheet is an Upper Frame that contains the wet concrete, and set the edge thickness of the panel. **Figure 3 shows** the pre-tensioned fabric membrane in place along with the upper frame and reinforcing, ready to receive the concrete.

When wet concrete is placed in this mold, the fabric membrane deflects downward creating three-dimensional tension curves between the supports provided and, in this case, producing the panel shown in **Figure 4a** and **Figure 4b**. Using this method, a single membrane can be used to form a wide variety of designs by simply changing the design of the intermediate supports below the reusable fabric membrane. **Figures 5 & 6** illustrate alternate designs using the same fabric membrane. Simple changes in intermediate support patterns will produce significantly different panel designs.

Figure 4a. The concrete panel on the left (foreground) is cast directly from the fabric formwork rig shown in Fig. 1. The Panel to its right was cast using this first panel as a mold.

Figure 4b. Close-up view of the surface texture of the "direct-cast" panel shown in Fig. 4a. The permeable geotextile fabaric formwork gives a sensual and immaculate finish.

Figure 5. Another “direct-cast” concrete panel produced from the same fabric formwork membrane illustrated in Fig. 2. In this case, however, intermediate supports were provided in a grid pattern.

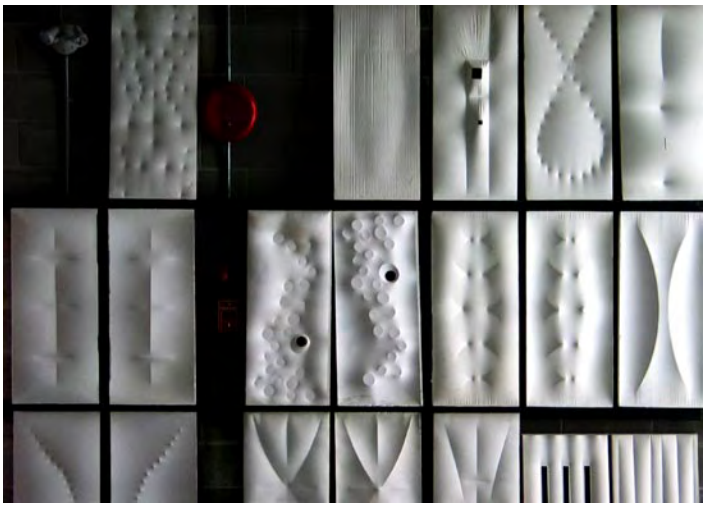

Figure 6. Plaster study models at the Centre for Architectural Structures and Technology: a large variety of panel designs can be cast from the same fabric sheet simply by changing the intermdeiate supports used in the formwork rig. Both "direct-cast" panels and inverse shell panels can be seen in this collction of models.

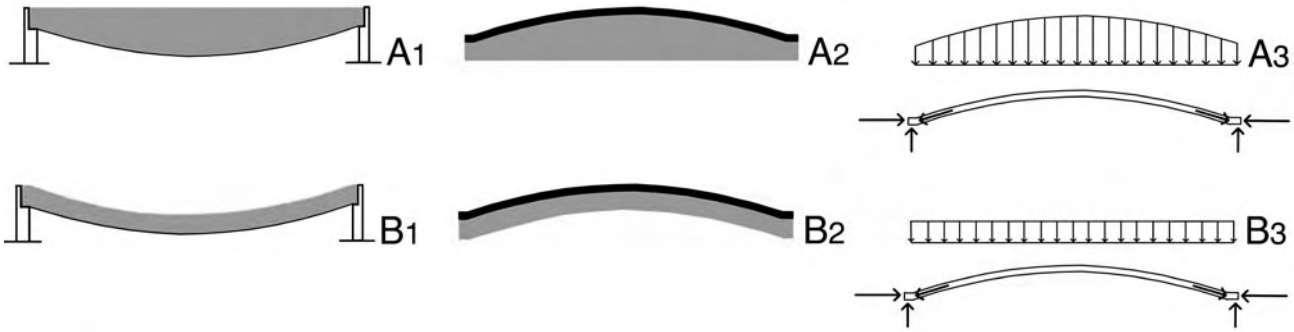

Figure 12. A1 is a vertical section through a direct-cast mold showing the funicular deflection of the formwork membrane. A2 shows the direct-cast panel cast in A1used as a mold to cast a thin-shell compression panel. A3 shows the loading pattern to produce pure compression in this thin-shell panel. B1 shows the same fabric membrane loaded with a uniform thickness of concrete. B2 shows the thin-shell panel cast from the B1 panel. B3 illustrates how this thin-shell panel will resist a uniformly distributed load in pure compression.

Figure 8. A “direct-cast” concrete panel being prepared as a mold for the "inverted cast" shell panel shown in Fig 9. The concrete of the mold panel is sealed and then coated with release oil prior to casting.

Figure 9. The Shell Panel on the left was cast from the “direct-cast” panel on the right (the same direct cast panel shown in figure 8).

Inverted Shell Panels: By natural law, inverted funicular tension geometry will produce a pure funicular compression geometry. By following this principle of geometric (and structural) inversion, a “direct cast” fabric-formed panel can be used as a mold to produce lightweight panels with structurally efficient compression shell geometries (see **Figure 7** above). **Figure 8** shows a direct cast panel being prepared for use as a mold to cast an inverted shell panel. **Figure 9** shows the Fig. 8 direct cast panel (right) and the shell panel cast from it (left). Shell panels can save concrete by providing structural shapes that allow minimal thickness at the apex of their vaults.

We have also produced two Glass Fiber Reinforced Concrete (GFRC) shell panels. Figure 10 shows the lower frame and intermediate supports for one such shell panel mold, and Figure 11 shows the mold it produced. Figure 12 shows the GFRC shell panel cast from this mold. This panel varies in thickness from 13 mm (0.5 in.) to (38 mm (1.5 in.).

Figure 13 shows another fabric-formed mold and Figure 14 shows the GFRC thin shell panel cast from this mold. Both the Figure 11 and Figure 13 molds were cast from the same fabric membrane and lower frame, though the Figure 13 mold uses only one longitudinal intermediate support, giving it deeper vault sections. The differences in these two molds are solely the result of different intermediate support designs placed within the lower frame.

Figure 10. Lower frame and intermediate supports used to produced the Figure 11 “direct-cast” panel, which in turn produced the Figure 12 GFRC shell panel.

Figure 11. Fabric-cast mold for the Figure 12 GFRC shell panel. This mold was produced from the Figure 10 intermediate support design.

Figure 12. Lightweight GFRC shell panel produced from the Fig. 10 “direct-cast” mold. This panel varies in thickness from 13 mm (0.5 in.) to (38 mm (1.5 in.).

Figure 13. "Direct-cast" panel used as a mold to form the GFRC inverted shell panel shown in Fig. 11.

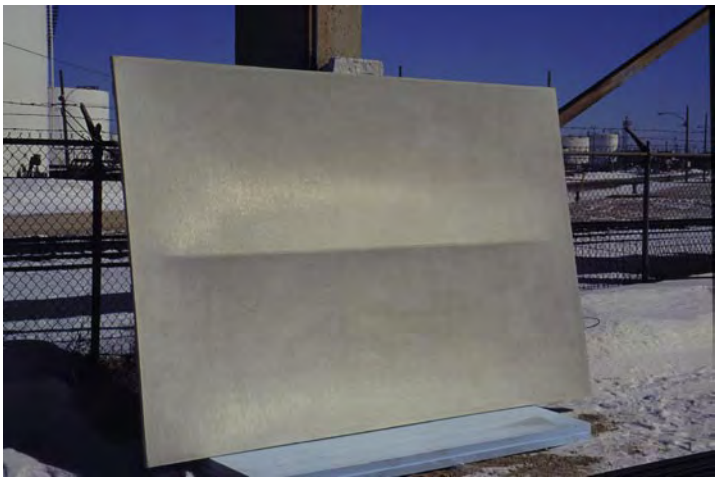

Figure 14. The GFRC inverted shell panel cast from the Fig. 10 "direct-cast" panel.

Figure 15. The “inverted cast” shell panel shown in Figure 9 (left) and cast from the direct-cast panel shown in Figure 8.

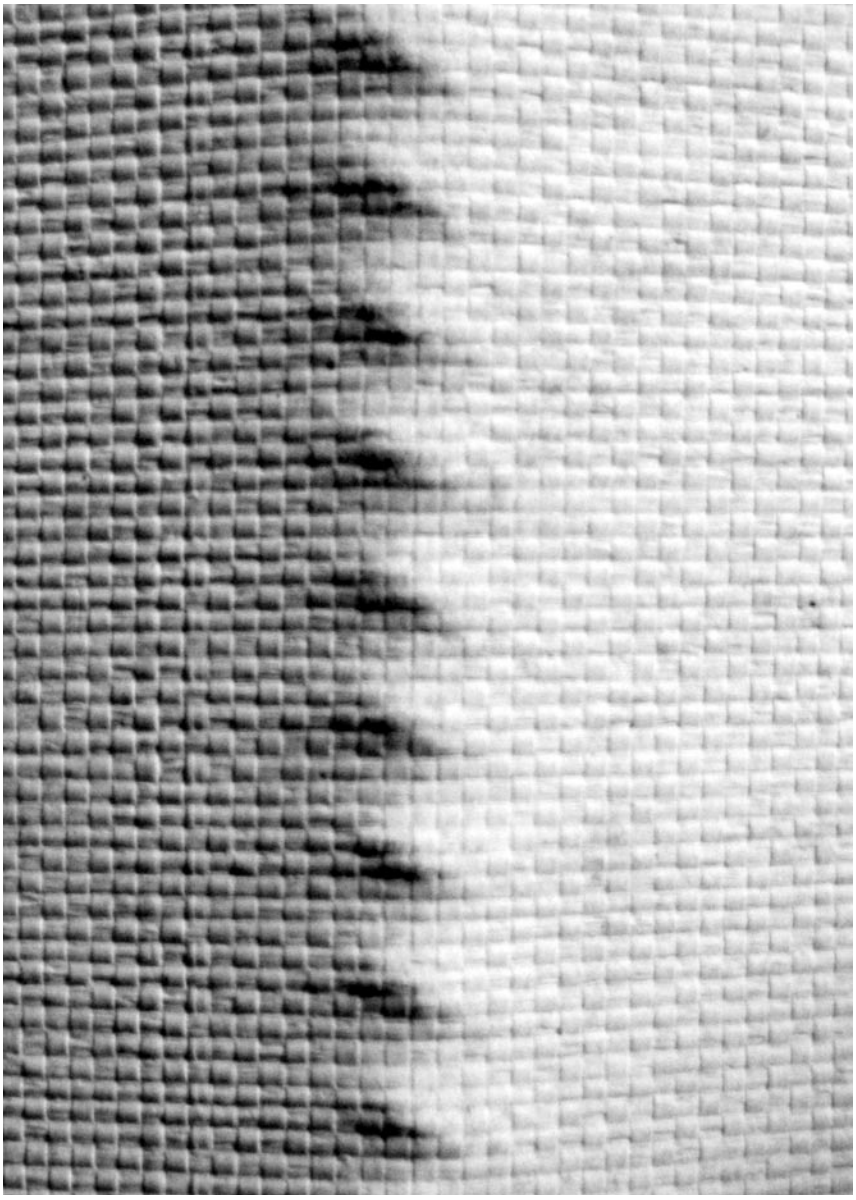

Figure 16. Close-up detail of the surface finish of the shell panel shown in Figure 15.

FORMWORK FABRICS

The flexible formworks described here used uncoated high density woven polyolefin (polypropylene or polyethylene) geotextiles for the formwork membrane. Woven polyolefin textiles offer several distinct advantages: 1) They are extremely inexpensive, costing pennies per square foot (less than one dollar U.S. per square metre) 2) They are very strong, they will not propagate a tear, and can withstand real abuse in the field (they are manufactured for use in road construction). 3) Concrete will not adhere to them, so no release agents are required in the casting process. 4) They can be reused much time over. 5) Permeable fabric formwork allows air bubbles and excess mix water to bleed out, leaving an immaculate surface with significantly increased compaction and strength. This produces a concrete surface that is both more beautiful and more durable than concrete cast in conventional water-tight molds. [

The primary shortcoming of these fabrics, with respect to their use in prestressed formworks, is that they suffer a significant relaxation of tension shortly after prestressing (a rapid creep). Heat of hydration may exacerbate this relaxation. This makes the calculation of both the prestress forces and in the membrane and their final deflections under load more difficult to predict. Other structural fabrics with true elastic behaviour do not share this shortcoming, however these textiles are more expensive and may not share the other significant advantages of the polyolefin’s. Composite textiles composed of polyolefin and, for example, glass fibres may be able to provide superior formwork fabrics.

CONCLUSIONS

A new class of beautiful precast concrete panels with better surface finishes and higher durability can be easily produced from simple fabric formworks. Though the method requires some new construction knowledge, the technique is not difficult to learn. Concrete, long considered by most people to be a hard, cold, and even brutal material, is re-born in flexible molds as a softer and sensual material that invites touch. The ability to easily form funicular

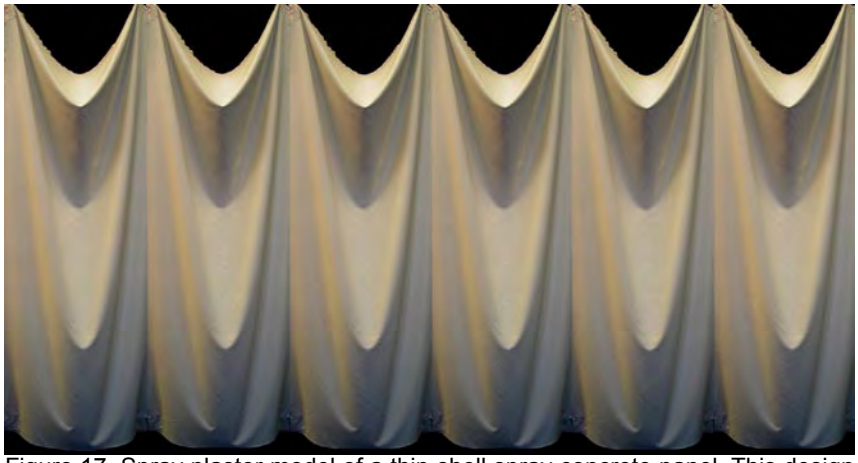

Figure 17. Spray plaster model of a thin-shell spray concrete panel. This design is produced by spraying a hanging rectangle of fabric.

Figure 18a. Model fabric formwork prestressed in a "cradle" rig.

Figure 18b. Spray plaster model produced from the Fig. 18a "cradle" rig.

Figure 19. Spray plaster model of thin-shell spray concrete panels.

Figure 20. Spray plaster model of a thin-shell spray concrete panel.

compression shell geometries from tension membrane formwork can provide reductions in concrete volumes compared to conventional prismatic (flat rectangular) panels. This can reduce both dead-weight and cement consumption, offering more sustainable concrete construction.

NEW DIRECTIONS AND EXPERIMENTS

In early 2007 the Centre for Architectural Structures and technology will begin full-scale trials of a new prefabrication method for concrete panel production using sprayed concrete applied directly to hanging or prestressed fabric sheets. This research is aimed at dramatically reducing concrete volumes by producing thin-shell panel structures, while producing even greater architectural freedom. This new technology has been successfully tested in small scale models using spray plaster to model full-scale shotcrete or gunnite construction (**Figures 17, 18a, 18b, 19, 20**).

CREDITS

This work was done at the Centre for Architectural Structures and Technology (C.A.S.T.), and at two precast factories in Winnipeg, Manitoba: Conforce Structure's Ltd., and Lafarge Canada Construction Materials Group, with financial support from the Canadian Precast Concrete Institute (CPCI), Manitoba Chapter.

The following students from the University of Manitoba's Department of Architecture designed and constructed panels used in this article: Michael Monette, Kenneth Borton, Andrea Flynn, and Jonathan Trenholm. The following students assisted in our research into the technology of producing fabric-formed thin-shell panels using spray concrete applications: Aynslee Hurdal, Chris Weibe, Leif Friggstad, Mike Johnson, Tom Alston, Kyle Martens.

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