New Exterior Envelope Assemblies Using High-Performance Textiles

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INTRODUCTION

The contemporary curtainwall has generally been assembled of discrete, rigid components. These assemblies are modular, substantially premanufactured, and highly tested systems meant to fully address the needs of a separation between the unstable exterior climate and the need for a stable interior environment.

Recently, the contemporary exterior envelope has been the subject of research that seeks to extend the performance of the system as an effective barrier for sustainable architecture [Daniels, Techology of Ecological Building] [Daniels, Low-Tech]. This research includes various efforts to develop responsive assemblies with the capacity to sense environmental forces and act to optimize performance [Compagno] [Wigginton]. In addition, much design thought has recently been focused on the possibilities for a contemporary expression of translucency and lightness based on a minimal material tectonic and analogies to the epidermal structures of living organisms [Riley] [Lupton]. All of these themes, and others, have placed a great deal of value on the prospects for new material assemblies for the exterior envelope. Textiles are a prime candidate for further study [Gregory][Mills][Walsh][Foulger].

Fig. 1. Chicago

Fig. 2. Curtainwall in construction

Fig. 3. Modern Yurt

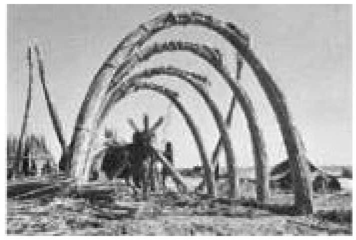


Fig. 4. Congolese building

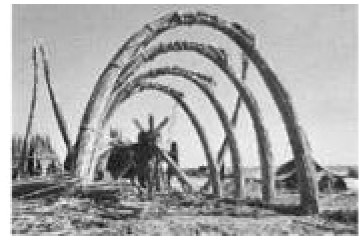


Fig. 5. Reed Building

PROJECT I: A MULTI-LAYERED HIGH-PERFORMANCE TEXTILE EXTERIOR ENVELOPE

The history of the use of fabrics in architecture, particularly as a primary component of the exterior wall, is rich and widespread over time, geography and climate. Recently, with the invention of high performance, polyvalent fabrics composed of newly engineered fibers new opportunities have appeared for lateral technology transfer to architectural applications [High Performance Fibers]. These new fibers and fabrics offer useful properties for exterior envelopes that extend the realistic and innovative use of textiles as a primary boundary material between the exterior climate and the interior environment. Multi-layered, insulated, lightweight and durable fabric exterior envelopes are now an interesting possibility.

The most common applications of fabrics in architecture are structural tensile membranes. The modern version of these tensile forms is a relatively new innovation in architectural form.

However despite a number of successful built experiments in structural fabrics, and precisely because of the limitations engendered by the necessities of the double-curvature geometry of many pre-stressed fabric constructions, there continue to be a very small number of building types that efficiently utilize the overall curvatures of these materials.

Given the obvious geometric difficulties to using tensile fabrics in many building types, it is worthwhile seeking orthogonal textile systems that can attend to the performance requirements of the contemporary exterior envelope.

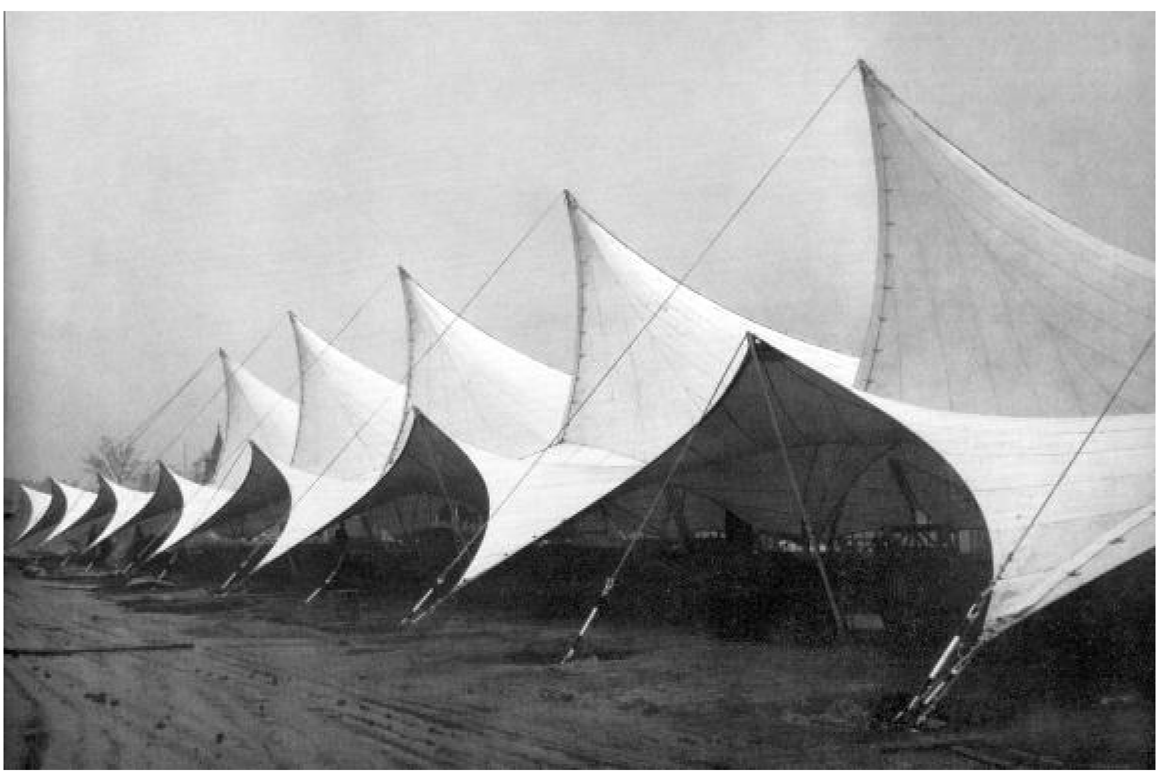
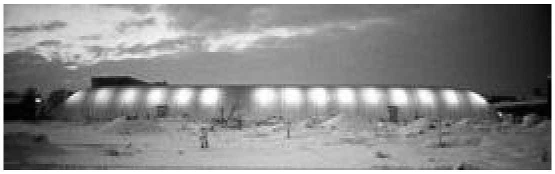


Fig. 6. One of the tents erected by Frei Otto for the1963 Horticultural Exhibition in Hamburg, Germany.



Figs. 7, 8 and 9. ASO Offices
Norman Foster and Partners


Figs. 10, 11. Waterworks Pavillion, Doncaster, England
Use of ETFE as an exterior envelope material [Robinson-Gayle]

Two obstacles currently exist for the application of high performance fabrics in an orthogonal architecture. First, the performance attributes of a multi-layered fabric system have not been adequately investigated. Second, the detail characteristics necessary for the successful restraint and assembly of an exterior envelope have not been addressed. This paper presents research that begins to answer these questions through the testing and development of two distinct exterior envelope systems using high-performance textiles.

Multi-Layered fabric wall assembly

The design illustrated below is an insulated rainscreen exterior envelope composed of a planar arrangement of multiple layers of various fabrics. The rainscreen is accomplished by placing an air barrier at layer B. Therefore the pressure equalization chamber is the air space between A and B. Layer A serves to allow a certain amount of air through its surface at a rate that accomplishes the pressure equalization necessary for

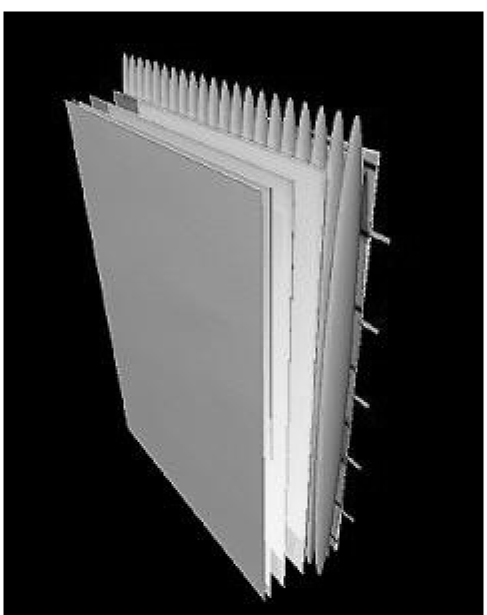


Fig. 12. Multi-layered fabric assembly

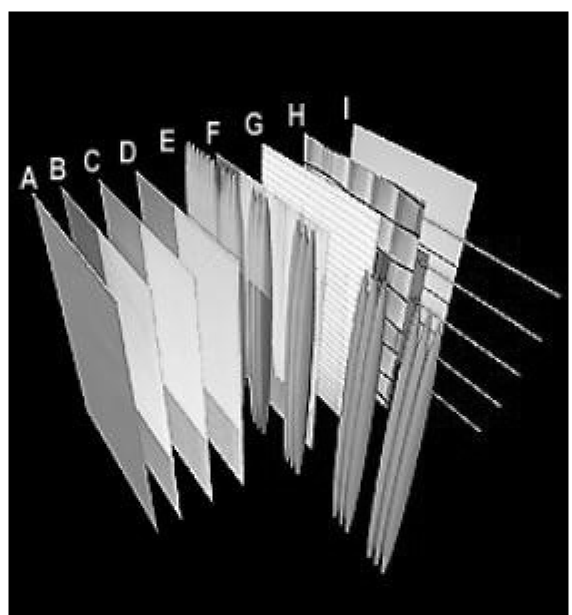


Fig. 13. Multi-layered fabric assembly exploded

Table 1: Preliminary specification of fabric layers

Layers	Performance role	Governing properties	Materials Notes
Exterior			
A	Exterior finish and mechanical barrier	Water resistant Vapor retarder U.S. perms ~ 0.8 – 1.4 CSI perms ~ 0.014-0.024 Tensile strength	Fiberglass w/ PTFE coating Polyester and PVC coating Teflon coated PVC
B	Air barrier	Impermeable up to 400 psi.	Nonwovens, mylar sheeting
C	Radiant barrier	Various	Aluminized polypropylene or mylar film
D	Insulation pocket (along with layer F)	Various	Ripstop nylon, polyester, mylar sheeting
E	Insulation	R-value: 3.5 per inch.	Recycled cellulose insulation, treated against biodegradation and fire resistant, contained within hermetically sealed pockets
F	Insulation pocket (along with layer D)	Various	Ripstop nylon, polyester, mylar sheeting
G	Vapor retarder	Vapor permeability U.S. perms ~ 0.025 CSI perms ~ 0.00045	Tyvek or other nonwovens
H	Flame resistant material	BOCA code Class I material, Noncombustible NFPA, ASTM E119	Mineral based non-woven
I	Interior finish and mechanical barrier	Tensile strength Ripstop strength	Lightweight raft paper and aluminum honeycomb sandwich panel Wheatboard or other biocomposite
Interior			

the successful behavior of the rainscreen. Other layers are listed in terms of their specific performance requirements in Table 1.

There has been substantial progress in the use of fabric membranes for several contemporary building types, especially as tensile fabric structures, however the development of architectural applications has not reflected the enormous innovations in fiber and textile science. The modern material science of fibers, primarily synthetic polymers, has yielded dozens of important textile materials and coatings that have come to dominate the primary textile market; namely, the consumer apparel market. Only a fraction of these new materials have come to find viable applications in the contemporary exterior envelope.

However, several fabrics have seen increased use in tensile structures. Table 2 lists the most commonly used materials for these applications.

Detail morphology and assembly characteristics

A typical curtainwall assembly is accomplished through the design of a set of distinct details appropriate to the materials used and the performance requirements of the system [McEvoy]. Textile materials require a reconsideration of the morphology of details necessary for a successful wall. The diagram in Figure 14 shows the conditions for which details were generated. The edges required the adaptation and invention of details that would continuously and efficiently restrain the end of the sheet material. The details for the condition require the transfer of a coplanar tensile load to the frame in all four sides. For relatively small areas, this tensile stress will be approximately equal on each of the four sides with the exception that the material weight of the sheet would be carried substantially by the upper horizontal. In addition, details were required that would allow for the incorporation of rigidity normal to the surface of the sheet material. This restraint is particularly important to restrict the movement of the fabric due to both sustained positive and negative wind pressure and surface turbulence. Typical fabric restraint details are shown in Figure 16.

A Tall Building Exterior Envelope System

The following design studies have served as a preliminary testing ground for solutions that are appropriate to the use of a multi-layered fabric exterior envelope. The design, featured in Figures 17, 18, is a hypothetical

Table 2: Widely used architectural fabric products

Trade Name	Company	Substrate fabric Weight Weave style Yarn count (warp fill)	Coating Weight (top, bottom) UV topcoat material UV topcoat weight	Finished fabric Thickness Weight	Strip tensile Warp Fill	Grab tensile Warp Fill	Hydrostatic resistance	Combustible characteristics	Light Transmission Reflectance Absorption	Applications Warranty
Air Tite 1532	Erez Thermoplastic	Polyester 270 g/m² weft insertion 19, 18 tpi	PVC 385 g/m², 330 g/m² PVC 295 g/m²	0.8 mm 970 g/m²		1200N 1120N	400 psi 280 N/cm²	52 sec. After flame, 58.9 cm char length	8-10% NA NA	Air & tensile structures, tension tents 10 years
Archifab	Fabrimax	Fiberglass 624 g/m² modified plain 15, 13 tpi	Silicone NA NA NA	0.88 mm 1101 g/m²		NA NA	NA	Class A	15% 75% NA	Air & tensile structures, tension tents, clearspans 10 years
Duraskin B 18089	Verseidag Indutex	Glass fiber-EC3/EC4 180 g/m² L l/l 2040, 2040 dtex	PTFE 355, 355 g/m² NA NA	NA NA		NA NA	NA	Class A, NFP 92503 MI BS476 Parts 6,7: ASTM E84, E108, E136; NFDA 701 small	NA NA NA	NA
Precontraint 1202 Fluotop T	Astrup	Polyester HT 1,100/1,670 dtex NA NA NA	Plasticized PVC NA NA NA	0.80 mm 1050 g/m²		NA NA	NA	BS 7837, CSFM, DIN 4102 B1, NFPA 701	15% NA NA	Air striuctures, permanent buildings, tensile structures 10 years
Sheerfill I	Saint-Gobain Performance Plastics Corp.	Glass fiber 18 oz./yd.² Plain 18, 19 tpi	PTFE 13.5, 13.5 oz./yd.² NA NA	0.036 in. 45.5 oz./yd.²	975 lb./in. 900 lb./in.	NA NA	NA	ASTM E 84, ASTM E 108 A ASTM E 136	7/11% 74/72% 5%	Air & tensile structures, tension tents, clearspans Project specific
Sheerfill II	Saint-Gobain Performance Plastics Corp	Glass fiber 14 oz./yd.² Plain 24, 19.5 tpi	PTFE ~12, ~12 oz./yd.² NA NA	0.03 in. 38.5 oz./yd.²	785 lb./in. 560 lb./in.	NA NA	NA	ASTM E 84, ASTM E 108 A with Fabrasorb liner, ASTM E 136	9/13% 75/72% 5%	Air & tensile structures, tension tents, clearspans Project specific
Shelter-Rite 8028	Seaman Corp.	Polyester 254 g/m² weft-inserted, warp knitting NA	PVC NA Tedlar NA	NA 950 g/m²	515 lb./in 515 lb./in	700 lb./in 700 lb./in	500 psi	CSFM, UL 214, NFPA 701, ASTM E-84, 2-second flame-out	NA NA NA	Air structures, tensile structures 15 years
Solus 1100 HT	Taconic	Glass fiber NA Plain NA	PTFE laminate Equal NA NA	0.80 mm 1100 g/m²	5000 N/5cm 5000 N/5cm	NA NA	NA	BS 476 Parts 3, 6, 7	55% 32% NA	Air & tensile structures, clearspans 10 years
Solus 1200B	Taconic	Glass fiber -EC3 NA Plain NA	PTFE Equal NA NA	0.65 mm 1200 g/m²	6200 N/5cm 5000 N/5cm	NA NA	NA	BS 476 Parts 3, 6, 7	0% 65% 0%	Air & tensile structures, clearspans 10 years
Vinagard 253-25	Vintex Inc.	Polyester NA 2-ply polyester weft-inserted NA	PVC NA Fluorofinish NA	NA 874 g/m²	NA NA	440 lb./in 400 lb./in	NA	CA1237.1 small, CPAI 84, NFPA 701-1996 test 2	NA NA NA	Air & tensile structures, clearspans, pole tents, acoustic liners

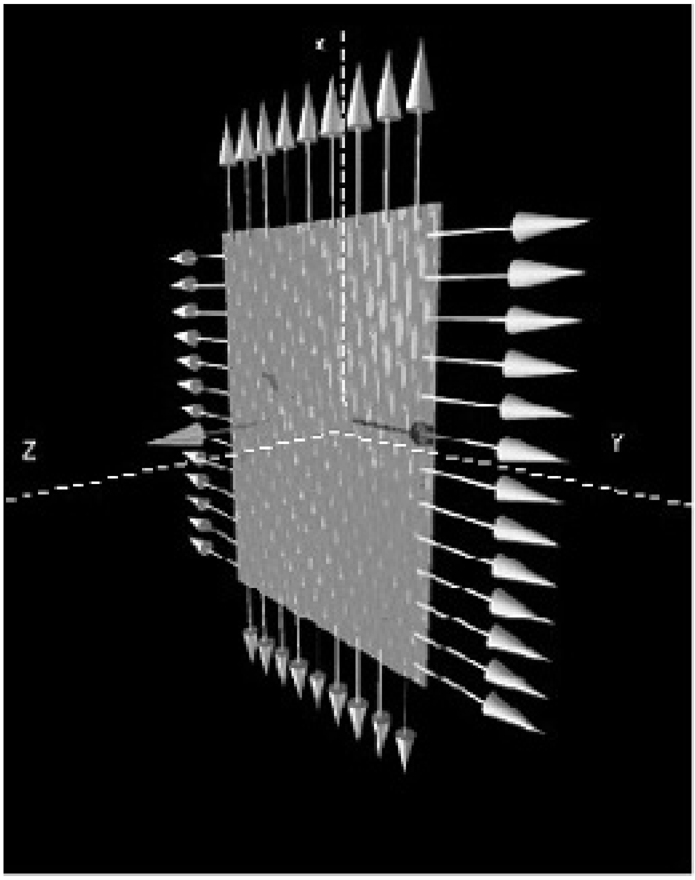


Fig. 14. Force diagram

tall building skin. While the tall building is a type that has been used to speculate on the use of fabrics in the exterior envelope, the use of a multi-layered insulated fabric wall has not been investigated. Most investigations have proposed the use of a tensile fabric network as the primary exterior surface material.

A Performing Arts Center

The two images below are perspectives of a schematic design of a small Performing Arts Center located in Harvard Square and using a multi-layered wall as the principle exterior envelope material.

In addition to the work, on multi-layered textile exterior envelopes, that has been accomplished and will continue, another project that involves textile materials has been undergoing a series of load tests to determine the load transfer behavior of a new kind of glass restraint system.

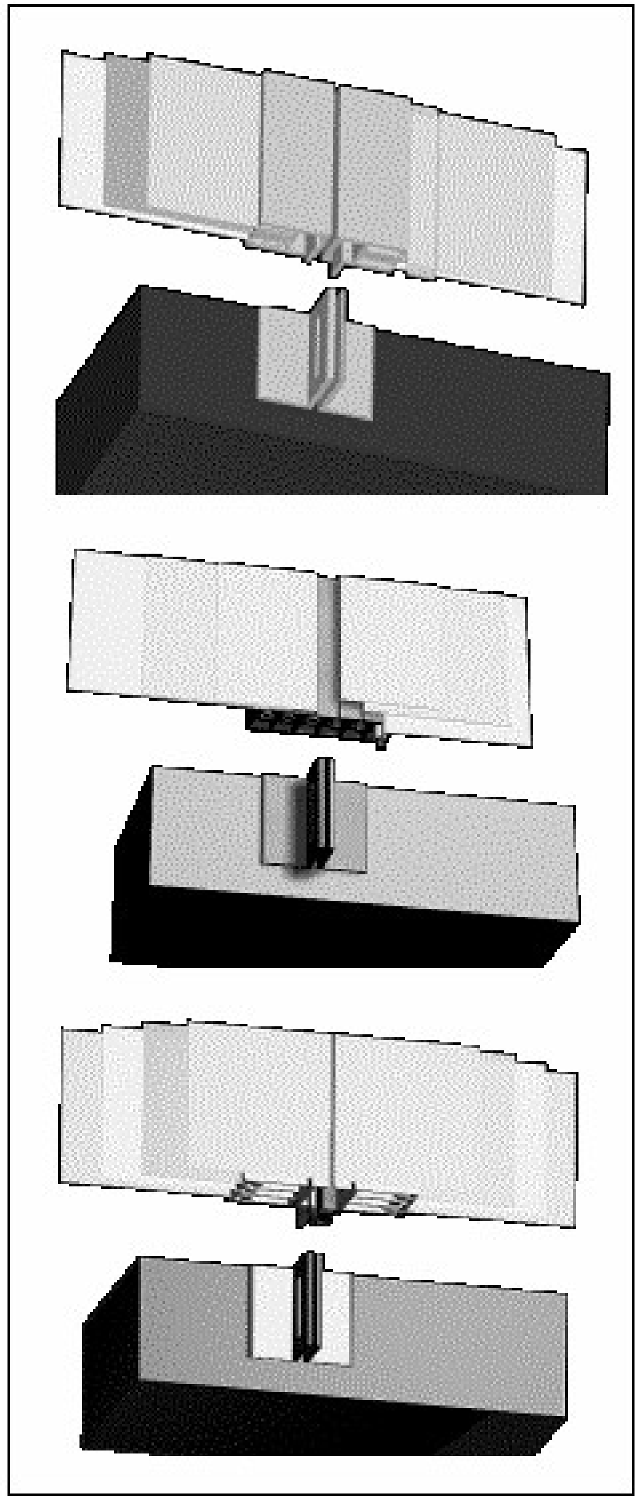


Fig. 15. Slab/typical mullion connections

PROJECT I: A LAMINATED GLASS AND HIGH-PERFORMANCE TEXTILE COMPOSITE FOR AN EXTERIOR ENVELOPE ASSEMBLY

The following pages describe preliminary experimental and design work for a new type of glass curtainwall.

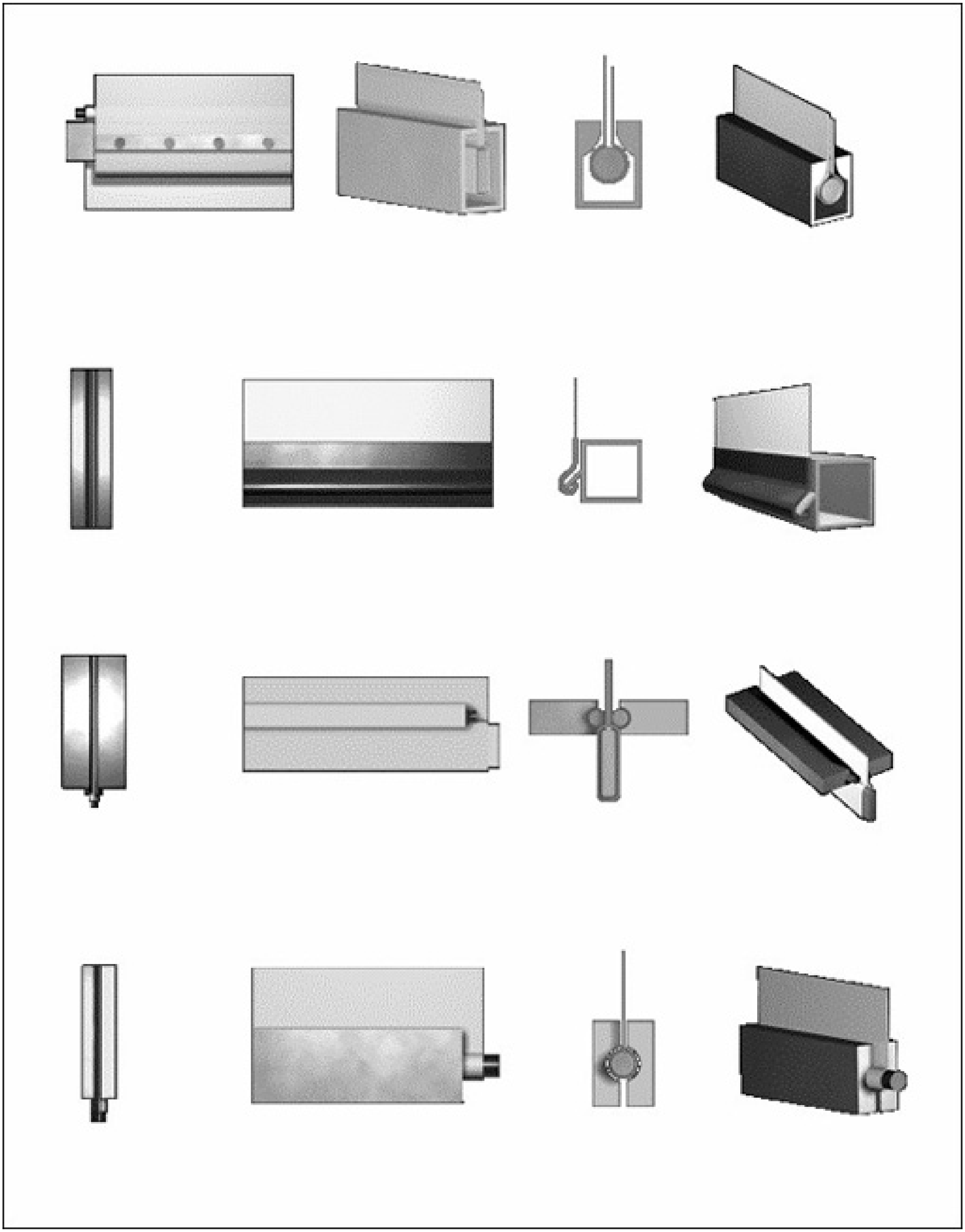


Fig. 16. Textile restraint details

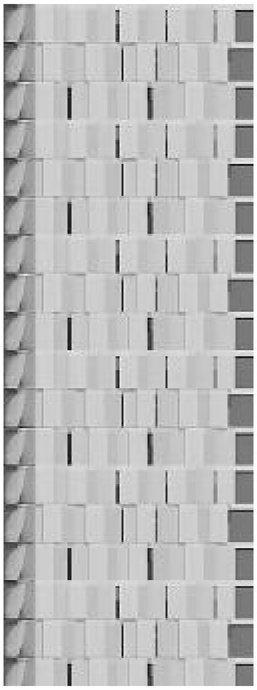


Fig. 17. Fabric wall design
Tall building application

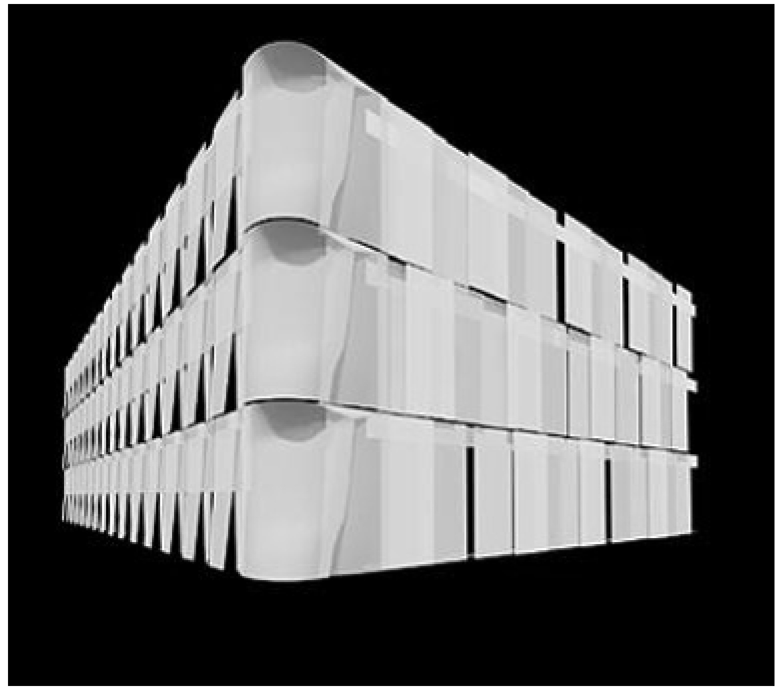


Fig. 18. Fabric wall design
Tall building application showing the open corner allowing for natural ventilation for cooling.

Using laminated glass and high strength fibers and textiles, the assemblies shown here depend on a textile reinforced interlayer as the primary structural component for vertically supporting and horizontally restraining the glass panes to the building structure. With the load testing of a series of samples, first results indicate good potential for further development of this type of assembly. The advantages of such a system include:

1. lighter curtainwall assemblies, requiring less structural support and simpler architectural details,
2. continuous structural restraint of a series of glazing panes, allowing for greater speed and ease of construction,
3. better protection against overall curtainwall failure from earthquake, blast and other catastrophic events, and
4. minimizing air infiltration by using the textile interlayer to better seal areas between glass panes.

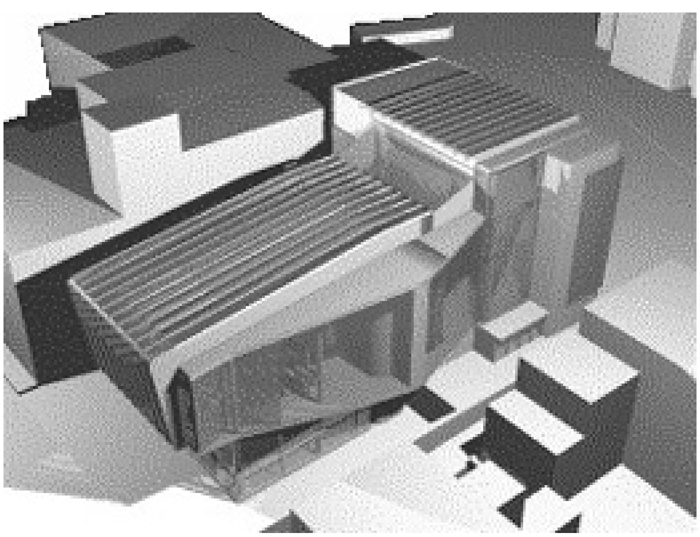


Fig. 19. Fabric wall design
Small-scale application of a multi-layered fabric exterior envelope

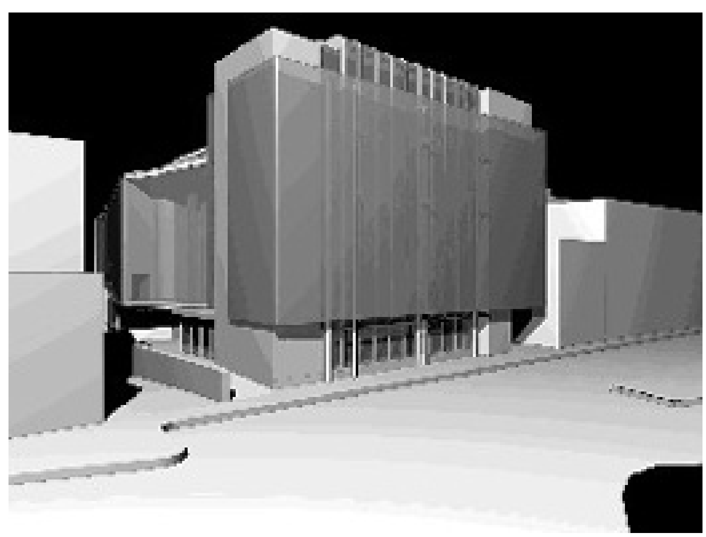


Fig. 20. Fabric wall design
Street wall elevation

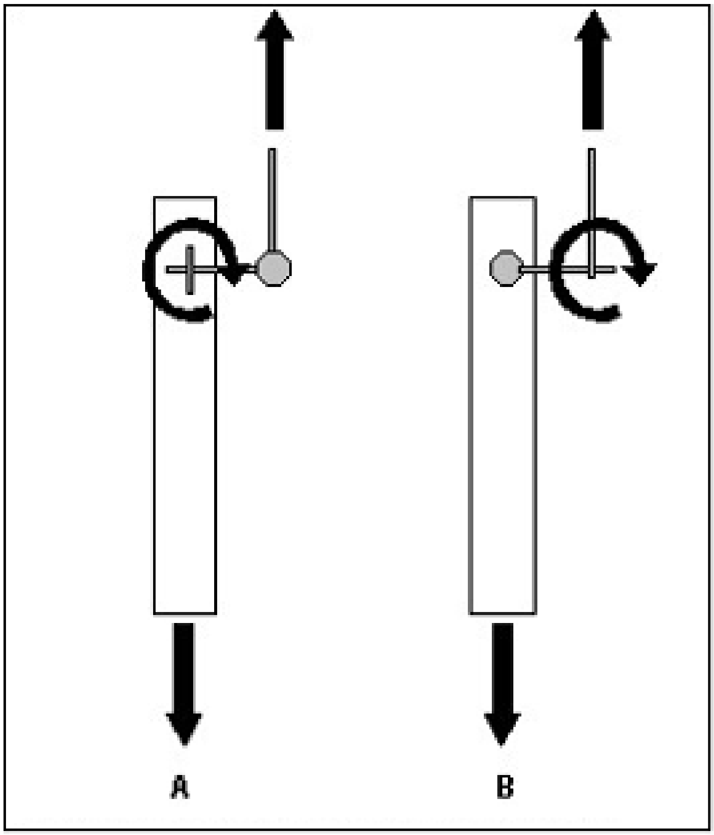


Fig. 21. Suspended glazing systems
A: stud system, bending in the glass
B: articulated bolt system: bending in the support

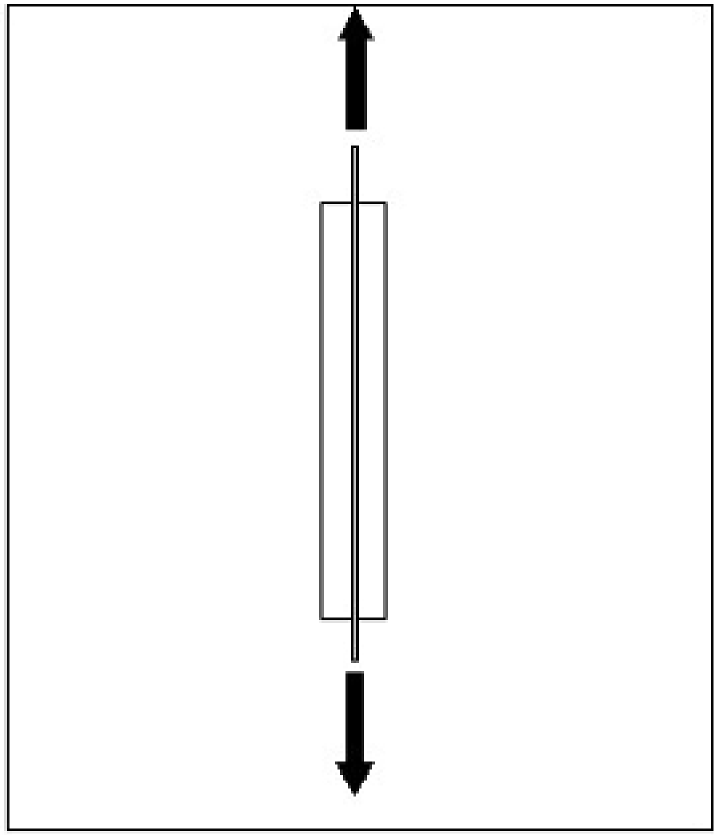


Fig. 22. Proposed suspended glazing system

This paper describes Phase I of a three-phase project. Phase I consists of the general examination of the capabilities of such an assembly and the essential detail requirements for continuous textile restraint. In addition, the structural properties of various interlayer materials will be investigated along with their thermal, solar and visual properties. Durability issues will be addressed through detailed design and specific environmental testing. Phases II and III will expand upon this work toward the development of a new generation of curtainwall type. These phases will determine proof-of-concept parameters and involve the design of various prototypes. Final products will include the complete description of the assembly details and specifications of a new method for attaching glass laminates to an architectural assembly with the use of structural laminates.

Introduction

Glass curtainwalls are assemblies of glass, aluminum, steel, insulation materials, vapor retarders, air barriers and other materials meant to form a consistent barrier between a stable interior and unstable exterior environment. Currently two methods are employed to support and restrain the glass pane within the curtainwall assembly. First, the most common method involves restraining the glass pane within a continuous frame. The glass is mechanically held on all of its edges and its material weight is transferred to the metal mullion frame. The lateral load is also transferred through the glass material and into the metal frame through to the slab edge. This kind of restraint employs mullions as the primary load transfer component.

The second method employs the technique of suspending a pane of glass from the structural frame of the building. This method has been referred to as the suspended glazing and point-fixing method [Schittich]. Two methods have been devised to transfer the load of the suspended glass panes to the frame. First, small clamps have been used to attach a pane to its neighbor and transfer the load to the frame. These 'patch' fittings were first used on the curtainwall of the Willis, Faber & Dumas offices, Norman Foster architect. Other clamps have been devised and now a great variety of examples exist for this kind of restraint detail. The other method involves drilling a hole through the glass pane and transferring all loads to a metal hanger. The most widely used system is the Pilkington Planar system.

Materials

Table 3: Structural textile laminated glass interlayer materials

Material Class	No.	Description	Functionality
Metal	1	Woven metals: aluminum, stainless steel, titanium, and others. Also thin woven cables and ribbons.	Provide tensile structural support and bonding in shear Provide resistance to blast events
	2	Woven metals of heat conducting and emitting fibers.	Provide heat source for perimeter heating
	3	Metal films	Provide structural and thermal radiating surface
Textiles	4	High performance fibers: aramid, glass, carbon, polypropylene, polyester and nylon	Provide tensile structural support and bonding in shear Provide resistance to blast events
	5	Metal/ textile combinations: steel and aramid fibers combinations	Provide tensile structural support and bonding in shear Provide resistance to blast events
	6	Conductive and responsive fibers: experimental capillary textiles containing responsive liquids for variable translucency	Provide wide range of responsive effects

Through-glass connections possess the disadvantage of creating moment forces at some point between the glass pane and the structural frame, Figure 21.

This project has been investigating a third method for restraining a glass pane within a curtainwall, Figure 22. With the use of laminated glass there is the potential of using the interlayer material to suspend the pane within a curtainwall assembly. Advantages to this system include the elimination of bending forces within the glass pane or the support component as the transfer of all loads occurs coplanar to the laminar composite.

In addition, the interlayer material may be used as an impermeable material eliminating discontinuities in the air barrier system of the curtainwall. These discontinuities, occurring primarily around window assemblies may be eliminated through the continuation of the interlayer material. Furthermore, it is possible to consider continuous interlayer materials from one pane to the next, insuring no gaps between panes.

Figure 23 illustrates the basic components of such a system of a high-strength textile interlayer sandwiched between two panes of glass.

An essential step in establishing the viability of such a system was learning a great deal about the failure characteristics of the laminate itself. Several samples were manufactured and tested through a direct tensile test applied to the textile interlayer.

Test results

Several specimens were subjected to a direct tensile test for the purpose of determining the general behavior of failure with respect to a range of textile materials. The samples were restrained to the load frame by placing the fibers between two layers of aluminum plate that was then attached to the load cell. The fibers were impregnated with epoxy resin and hardener and placed between the two aluminum plates. The inside surface of the aluminum was sandblasted to achieve a rough and porous surface for a better adhesive seal.

Three types of industrial fibers were chosen for the first round of load testing: 1) e-glass, 2) carbon fibers and 3) aramid fibers, Table 4. These three fibers provided a range of tensile strengths. Two kinds of weave were also tested; a loose 'grid' of individual bundles of fibers and a tightly woven fabric, Figures 26 and 27.

Load testing results revealed that the aramid fibers performed the best overall, both for ultimate strength and the character of the load/strain curve. The load/strain curve shows an initial yield point that leads to secondary yield points before complete failure of the laminate. This indicates a complex failure mechanism in which catastrophic failure is avoided (see curves for samples 11, 12, 14 and 15 in Figure 33).

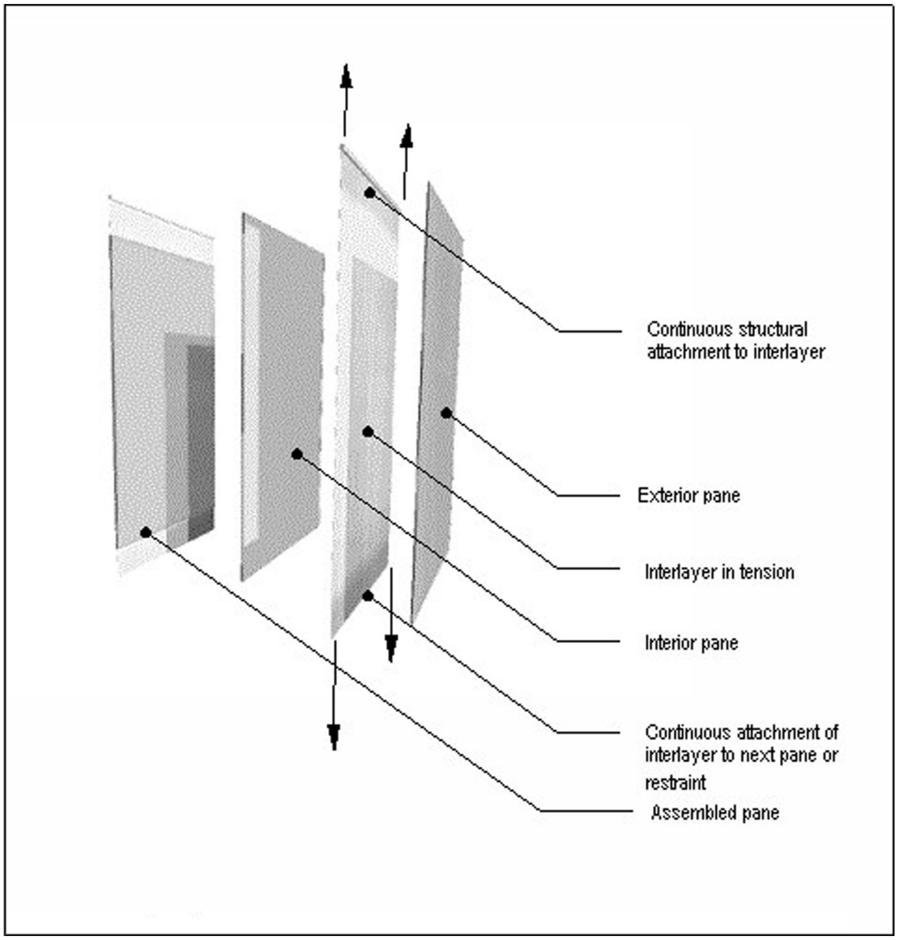


Fig. 23. Basic assembly components

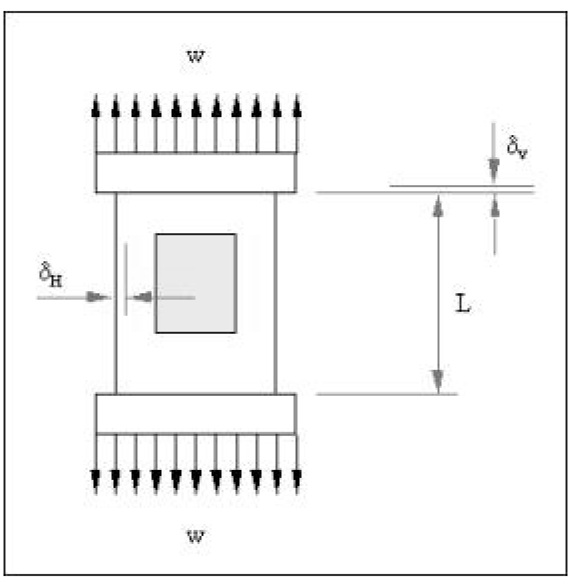


Fig. 24. Direct tensile testing setup

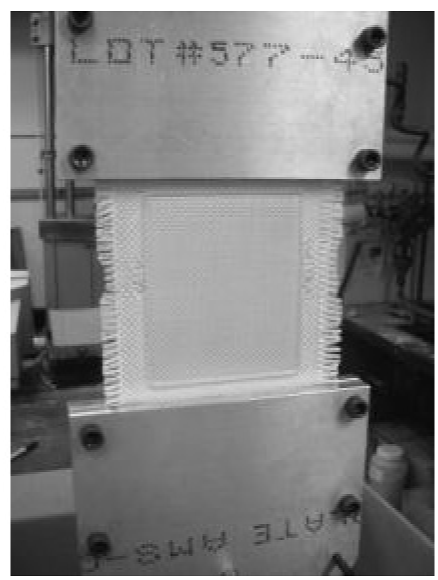


Fig. 25. Direct tensile testing setup

Conclusions

This paper has attempted to render an overall picture of the use of new textiles in the making of innovative exterior envelope systems. Textiles can be best brought into the design of sophisticated architectural assemblies through both technical and design-oriented research. Each of the two assemblies described here has required

Table 4: Interlayer materials

Material	Tensile strength ksi	Modulus psi	Density lb./in^3
Glass, E-grade 0.4-12 micron monofilament, f	297.3	12.3 x 10^6	0.093
Carbon fiber, high modulus 5 micron	349.5	55.5 x 10^6	0.065
Aramid fiber (Kevlar)	520.1	27.5 x 10^6	0.053

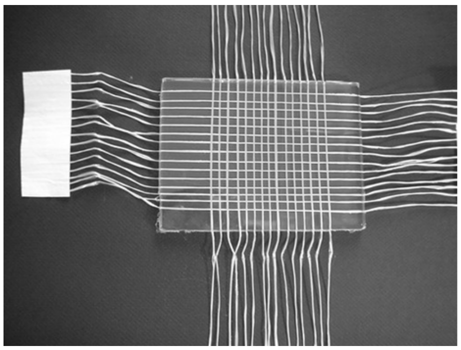


Fig. 26. Grid-type fiber interlayer

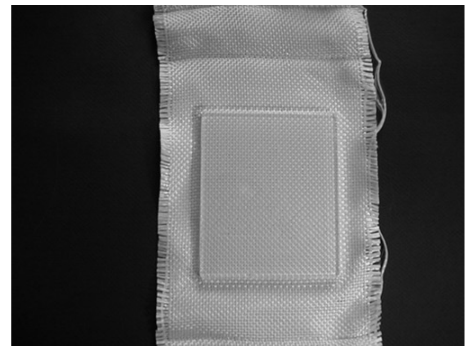


Fig. 27. Woven textile interlayer

a particular research approach to make it viable for improved buildings. In both cases, significant positive attributes have been discovered and nurtured toward providing a new way of producing successful exterior envelopes.

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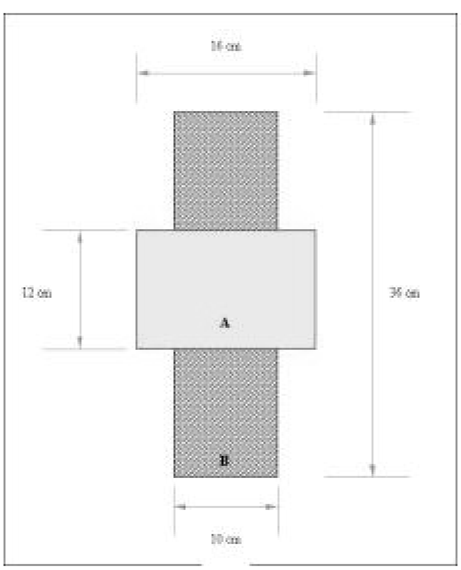

Fig. 28. Sample Type 1

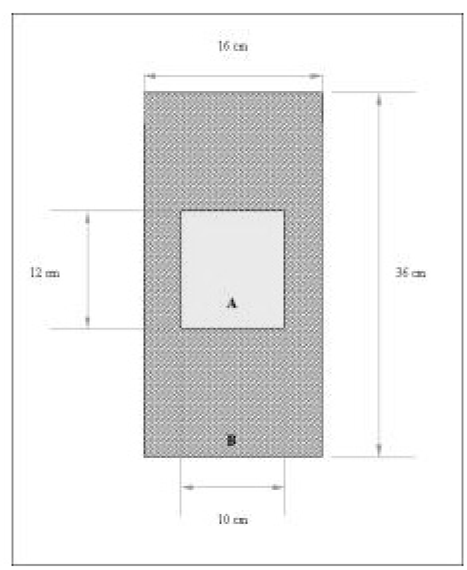

Fig. 29. Sample Type 2

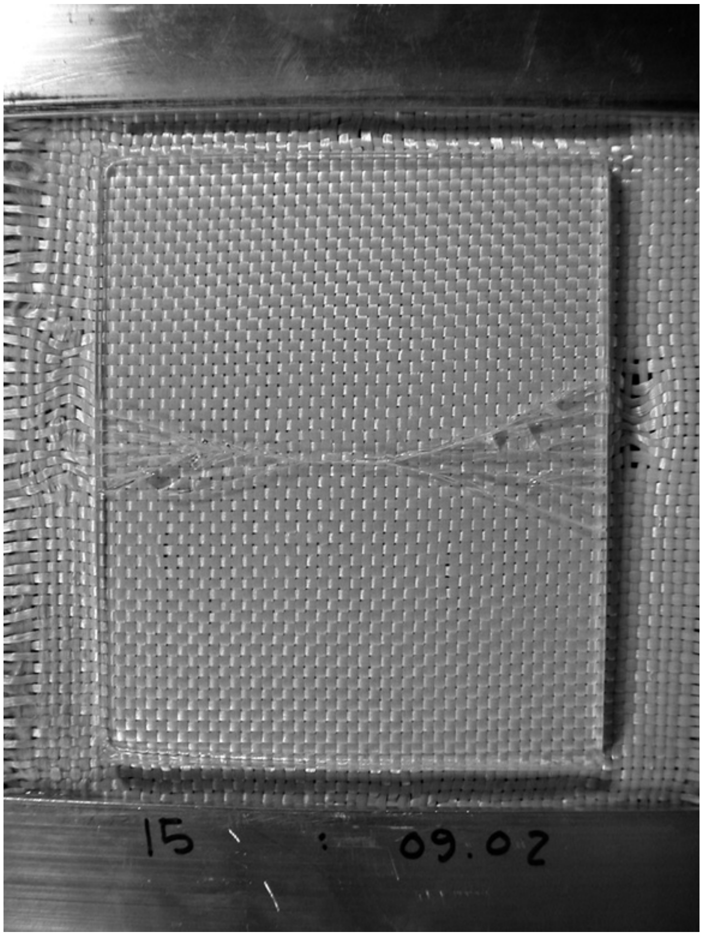

Fig. 30. Specimen 15, side 1: Aramid textile/PVB interlayer Fracture pattern after failure

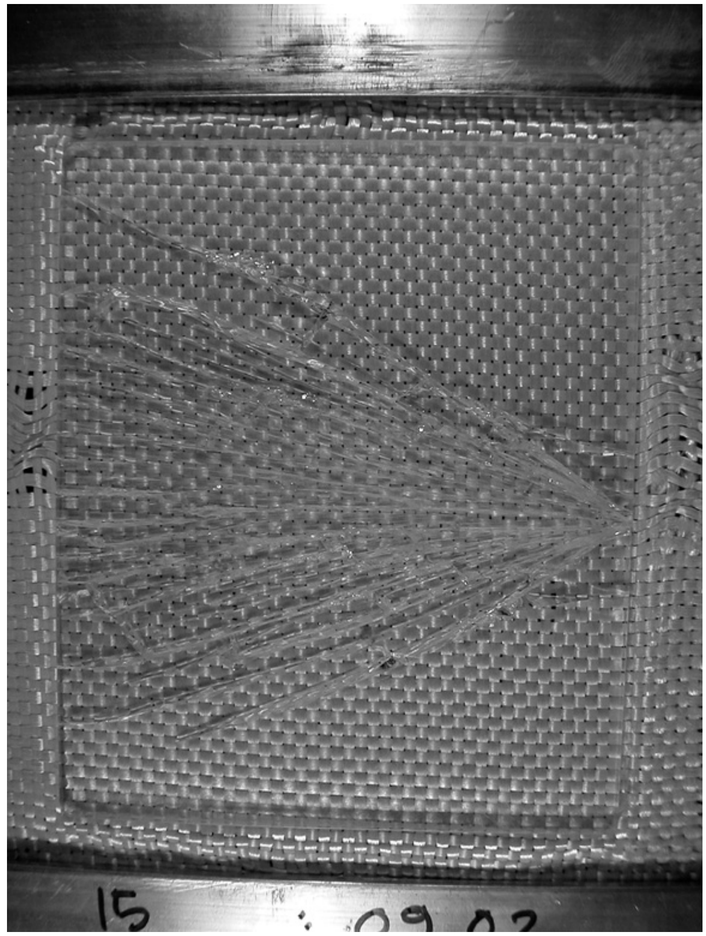

Fig. 31. Specimen 15, side 2: Aramid textile/PVB interlayer Fracture pattern after failure

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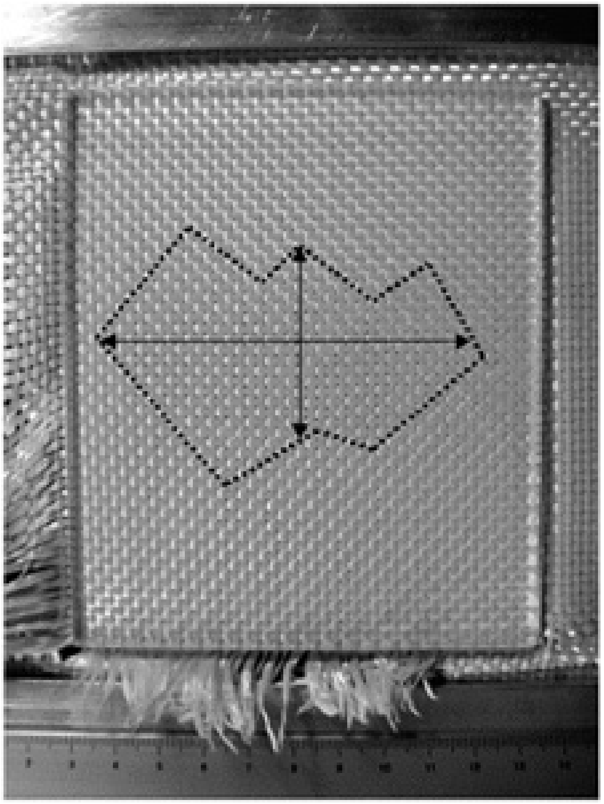

Fig. 32. Sample 11: Aramid textile/PVB interlayer
Dashed lines outline area of delamination before falure of textile

Table 5: Tested samples

Sample	Material A: aramid C: carbon E: e-glass	Weave type		Sample type	
		Loose grid	Tight weave	Type 1	Type 2
1	C		X	X	
2	C		X	X	
3	C		X		X
4	C		X	X	
5	C		X		X
6	C	X		X	
7	C	X		X	
8	A	X		X	
9	A	X		X	
10	E	X		X	
11	A		X		X
12	A		X	X	
13	A		X		X
14	A		X	X	
15	A		X		X

Note: No data was recorded for samples 6 and 7.

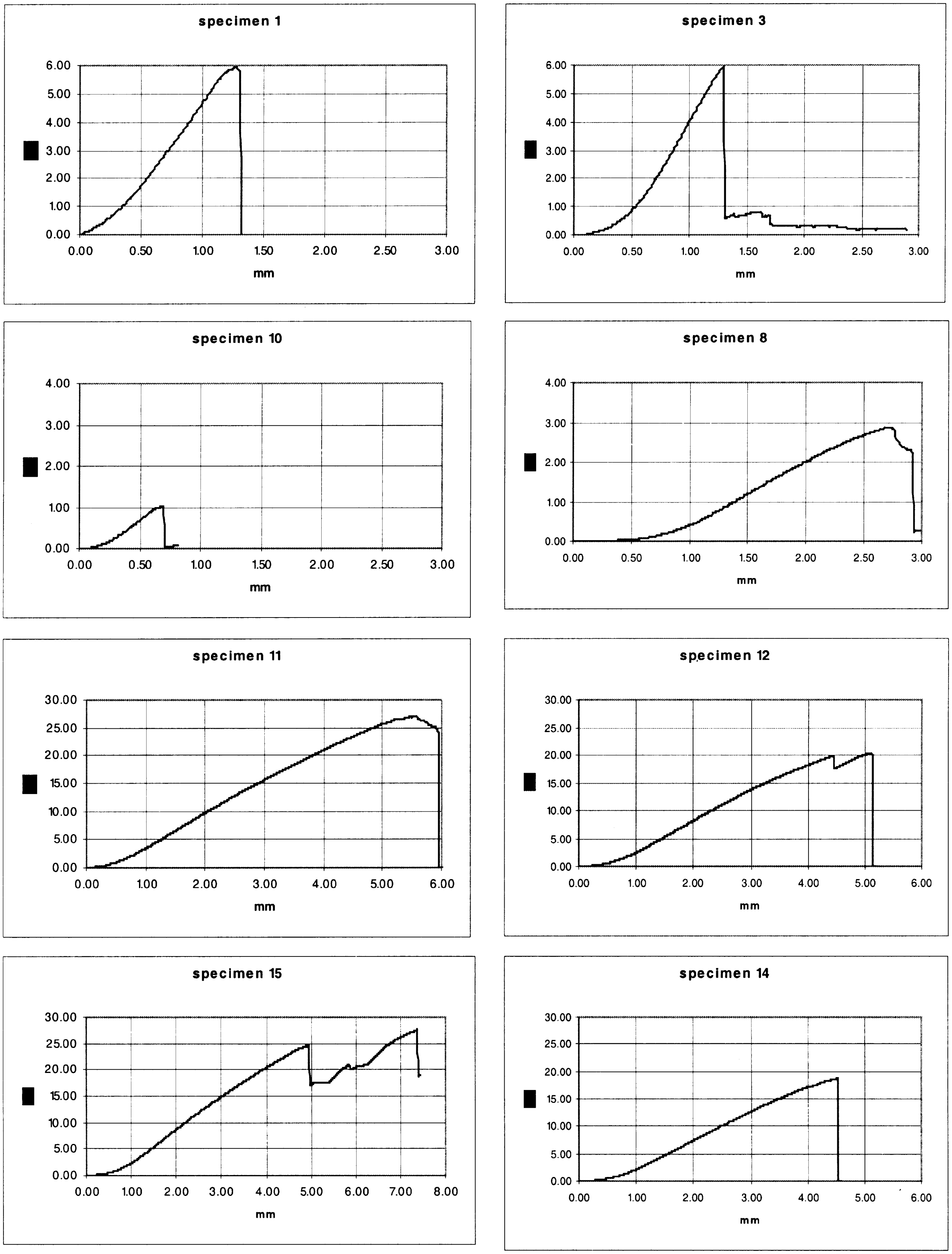

Fig. 33. Load results