Architectural Trends thru the Looking Glass

Charles W. Bostick
Consulting Architect

Introduction

Of all the traditional major building materials, wood, stone, masonry, metals, concrete - glass is probably the only one where significant technological advances are still being made.

Major advances in most building materials came in the 1800's – with the development of modern structural calculations - what we call statics, the efficient production methods of making steel and the development of reinforced concrete. Glass, however, was always relegated to being used as a simple infill panel contributing its special quality of transparency to the enclosure but not the structure (though there are 19th century buildings where glass does take structural loads, though most likely unknowingly to the planer and builder).

Glass did not come into its own until the middle of the 20th century with the invention of float glass (without which we would not have a reason to hold this conference on glass) and subsequently the incremental advances in glass coatings, milling, insulating units, but it wasn't until the end of the last century when, with the development of computers and programs that could finally easily handle the specific structural statics of finite element calculations, did glass start to break out of its traditional use as an infill panel.

The current on-going trends and technological advances in the use of glass are as a result exciting and many. The list is long and completeness certainly unachievable, but here is an attempt to look "thru the looking glass" at most of the newest developments in architectural glazing:

Glass Usage

The good news: usage of glass in architecture is up !
The bad news: there are probably two big factors for new buildings today that could steer owners and designers away from using a lot of glass:

A. Energy considerations
B. Cost

Full height floor to floor glazing brings more daylight into a building and more views out of the building – a plus for the human inhabitants, but at a cost of heat gain in the summer and heat loss in the winter. Add to that the fact that glass, to accomplish the same size enclosure, simply costs more than concrete or brick.

Solving these two problems is the next trend for glass as a material in architecture.

Luckily the industry is stepping up to the challenge with new technology, which in turn is leading to new uses – these uses sometimes requiring new technology – a cycle of innovation.

Glass Trends

- But where are the challenges?
- In what direction should the industry go to develop new technologies?
- What do the planners and designers want?

a. More glass, more transparency

The major cutting edge trend towards more and more transparency will continue.

Architects, planers and designers want to minimize the façade to just glass.

And here is a part of the future of the glass industry. In my work advising architects, structural engineers, façade consultants, helping them plan their visions, how many times did I get a phone call with the admonition: "We drew up a façade of so and so dimensions without any mullions. Can it be built?". The answer was usually, "Of course it can!" Glass should not be under estimated.

Let me give you some examples:

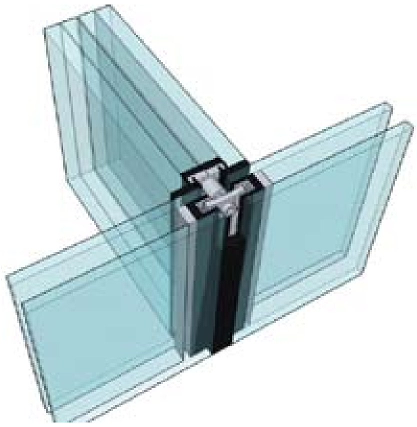


Figure 1

Glass fin mullion with "hidden" toggle connectors (image courtesy of seele)

I Glass fin mullions with hidden connectors

Glass fins are in more use than ever, usually with spider and button connectors but some architects demand even less and the industry is responding with "hidden" connectors that rely on bonding and clamping rather than drilling and bolting.

II Transparent glass cube

Ever since Mies van der Rohe's Farnsworth House architects have been dreaming of structures and enclosures that are even more transparent and filigree. There are a number of glass cubes, rectangles, tubes, cones on the designers' drawing boards – the Apple Flagship Store on 5th Avenue in New York City gave this movement a boost by setting a new standard.

Figure 2

Apple 5th Avenue Flagship Store, New York City (Bohlin, Cywinski Jackson) images courtesy of seele

Figure 3

Cutty Sark Museum (Grimshaw Associates) images courtesy of seele

Figure 4

Lincoln Center Alice Tully Hall (Diller Scofidio + Renfro)

III A glass bubble for a Ship's Museum

A design by Grimshaw Associates that provides the museum visiter with a view of the wooden hull up close using double curved self supporting glazing – pushing the boundries of both transparency and geometry.

IV Three stories of mullionless glass fin curtain wall

Maximum transparency over 3 stories with a view to the practice rooms of Lincoln Center in New York was the concept that pushed the detailing to a minimum and the size of the glass fins to a maximum.

b. More complex geometries

The second largest trend amoung deisigners of buildings is the use of more and more complex geometries, brought about by the advent of CAD use in producing drawings as well as advance statics programs to analyse the structures and made technically and economically possible by the use of CAD-CAM in the manufacturing process.

Some of tehse structures are even economical enough that I am sure we will be seeing more and more of them. Some projects that have been completed in the past couple years:

I The Main TGV-Train Station in Straussbourg, France

Where the shape of the wintergarden is a section of a doughnut or a torus where RFR ourt of Paris was instrumental in making sure the glazing enclosure worked. For this project cold formed glass that was curved before it was laminated was used.

II Undulating glazed roofs

Roofs that undulate are being used more and more to cover spaces such as at the Westfield Shopping Mall outside of London. The design concept was a "surface of water into which a stone was thrown and the resulting concentric ripples 'frozen', the concourse roof being cut out of the overall geometry. To achieve this geometry the roof over the mall concourse was originally designed as a membrane enclosure, but the owners decided that the advantages of glass outweighed its higher costs.

The 13,000 square meters of double curved geometry requires triangular glazing units of which no two are the same so that the glazing units and mullion members, being assembled on site like a kit of parts, are managed by advanced logistics software.

FIgure 5

Straussbourg Train Station (RFR Engineers, Paris) images courtesy of seele

III "dented" skylight dome

Even standard skylights are now being tailored to unconventional forms, like the conservatory skylight planned as a focal point for the retail part of the new Echelon Resorts Casino in Las Vegas. Here complicated computer analyses of the structure as a "gridded shell" helps lighten the steel mullion members.

Figure 6

Westfield Mall, London (Ian Ritchie Architects) images courtesy of seele

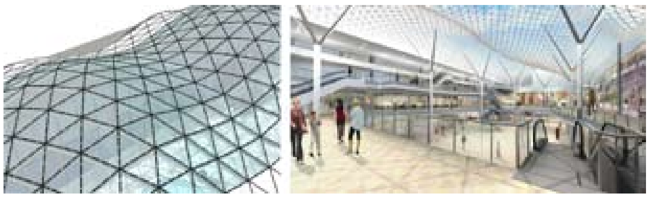


Figure 7

Echelon Resorts (Ian Ritchie Architects), images courtesy of seele

Figure 8

Wagram Hotel – Paris, France (Atelier Christian de Portzamparc), images courtesy of seele

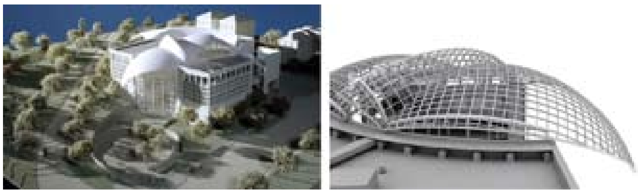


Figure 9

United States Institute of Peace, Washington D.C. (Moshe Safdie Architects), images courtesy of seele

IV Undulating facades

The French architect, Portzamparc, designed a hotel with a wavy IGU façade – possible despite the usual requirements of thermal and acoustic separation.

V "Wing" shaped glazing

Even 'free' form roofs are being conceived and executed, such as Moshe Safdie Architects' project for the U.S. institute of Peace where the image of a dove comes to mind for the curved atrium translucent glazed 'dome'. A challenge due to cantilever as well as wind and bomb-blast loads that effect everything from glass unit to glazing fastener and mullion construction.

VI An "snow drift mountain" facade

Antoine Predock's proposal for the Canadian Museum of Human Rights in Winnepeg imitates the ice, fog, snow and rock of mid-western Canada while at the sametime specifying thermal insulation values that will require either a very advanced double glazing or even triple glazing to meet the demands of the northern winters.

Glass Units

Since Sir Alistair Pilkington invented the float glass process in the 1950's a revolution in glass unit fabrication has been and is still going on.

The bad news: the economy is getting worse.

The good news: the economy is getting worse.

I believe (and have already heard from within the industry) that the current economic downturn will spurn new innovation. During the last couple years, glass manufacturers have been very busy trying to complete an above average amount of work on a flood of projects. This has lead to a slow down in the research & development departments as this manpower was needed elsewhere. Now, with more time on hand and the need for innovation in order to stay competitive, we should see in the next couple years at least a few significant new ideas in glass applications as well as further improvements in the way glass has been used to date. Here are a few of the newest trends in architectural glazing as I see them:

The following are a few of the latest innovations and trends in glass unit manufacture:

a. Coatings

I Thermal and Shading

Beginning in the 1980's coating technologies made huge advances.

Glass coatings are essentially thin mirrors – so thin that they don't reflect totally but let light – and vision – thru.

The early gold and mirror coatings from the 60's and 70's were replaced (at the urgings of architects) in the 80's by one molecule thin silver soft coatings tailored to let as much visible light thru as possible but reflect as much non-visible light (and heat energy) as possible. The latest coatings that have come out onto the market are the result of refinements in the molecules as well as production quality control so that the best quality thermal values for what almost appears to be a normal pane (other than a slight neutral grey tint with a bit of reflection) are now somewhere around 25% for sunshading combined with around 54% passage for vision light if used on surface number of an insulating unit. The goal here is to block as much sun heat gain but let as much daylight in so as not to have to turn on the lights (thereby heating the building as much as if more sunlight was let in).

The development of better hard coatings has increased the possibilities of glass build ups – allowing the coating to be on surface number 2 where a laminated outer unit is required, thereby improving the glass values.

II Frits and patterns

The latest, not so new, development which hit the market just after the turn of the century in ceramic fritting is probably the use of ink jet technology to "spray" the ceramic glaze on sheets of glass to create seemingly unending patterns without seams and do so with minute dots for more detail and softer color and pattern transitions – removing the traditional limits of silk-screening – a maximum manageable size of screen and a minimum dot size of around 1mm due to minimum screen mesh sizes.

Another most recent development is an extra hard and durable ceramic frit for surface number 1 – the outside surface exposed to weather and maintenance cleaning – that Eckelt, Austria has put out on the market in response to architects demands for a pattern that is more visible on the outside of the façade.

Here there is certainly room for new technologies. One can imagine, for example, what it would mean if some of the current semi-conductor technologies

Figure 10

Canadian Museum of Human Rights – Winnepeg, Canada (Antoine Predock Architect)

- solar cells, LED's, etc. – could be applied to a sheet of glass as a ceramic frit.

b. Insulating Units (IGU's)

I Gas filled

The demand for high performance thermal insulating glazing has led to a greater use of inert gas fillings for the IGU's air space or spaces. There is a movement among planers to specify the better performing (but more expensive) krypton gas over the more common argon filling. Here there have been some projects that have had to go with argon as the production and supply of krypton has not kept pace with recent demand. Manufacturers would be well put to increase production of krypton gas to meet this demand.

II Triple (and fourple?) glazing

With all the talk of "green architecture" and tightening of energy codes, the use of triple glazing is coming more and more to the fore. The first highrise building with a façade using triple glazing was the Highlight Towers project in Munich completed in 2005 – a first due to the size of the project and one which showed the industry that it would pay to invest in new production lines – much the same as what happened in the 1960's with double glazing, it is expected that once production lines for triple glazing become the industry standard the costs of triple glazing should be much the same as for double glazing now.

The insulating values that can be achieved with such glass with the addition of coatings and other innovations are approaching that of a standard insulated brick wall. This has caused some new phenomena such as office building windows that frost over in winter like car windshields, so that when one gets to the office in the morning there is no view to the outside until the sun hits the window.

The next step will certainly be four times insulating units – there are already projects using these units – a definite alternative to the traditional insulated opaque wall.

c. Glass edge spacers

There has been a search for alternate IGU edge spacers that are better insulators, thereby bettering the glass unit values. In the 1950's and 60's when modern IGU's were created, all sorts of edge spacer materials were tried out (including wood) and aluminium won out due to its low cost and easy forming characteristics. Now its high thermal conductivity is turning out to be undesirable and the industry has revisited some of those early materials in the search for better thermal performance. The latest development here is a return to steel, whether galvanized, tin plated, or stainless steel (a poor conductor of heat), but also the use of new materials such as polymers and foamed silicone, have come to the market.

Some of these "new" (old) materials have advantages over the traditional spacer – for example foamed silicon is soft, not like metal spacers, so it can "bounce" back when hit by large short term loads such as wind gusts. It provides slightly better sound insulation than metal spacers, plus it is easier to fit odd glazing shapes including curved units.

Manufacturing has for a while now tended towards bent instead of welded or bonded corners to improve the corner joint seals. A variety of colors have also been introduced at the demand of architects (black being the most popular if the building owner is willing to pay the slight extra cost).

d. Laminated glass

I Structural interlayers

Probably one of the most significant new products in the glazing industry is the polycarbonate interlayer for laminated glass. High strength polycarbonates – not to be confused with acrylic sheet - were developed in the 1960's, particularly by GE Plastics, but used mostly as a clear sheet product to replace glass – lighter in weight and more impact resistant than glass, the clear plastic sheet was not as scratch resistant nor as color fast (it tends to yellow with age) and not as fire resistant (being a petroleum product) as glass. In the 1990's DuPont developed a polycarbonate sheet (called Sentry Glass Plus or SGP for short) that bonds structurally with glass – providing the missing tension member in glass as a material being sandwiched in a laminated unit (much like the use of steel rebar in concrete) and many glass manufacturers/contractors have since been using this new found structural capability to take glass structures farther than could have ever been considered in the past. This is revolutionizing the use of glass fins, glass beams, self-supporting glass facades and skylights - glass benches, bridges and whole buildings such as the Apple Flagship Store's cube on 5th Avenue in New York City. Brand new ideas such as insulating units with mullions integrated in between the glass panes to make them "disappear" – in effect mullionless self supporting facades – with vertical spans of up to 6, 8 even 10 or 12 meters possible.

II Printed interlayers

With the application of jet ink printing to laminated glass interlayers, the possibilities of size and detail of patterns or images on a pane of glass have considerably increased. Limits of 1mm minimum dot patterns are dissolving as the manufacturing equipment for this type of patterning is being adopted in the glass industry. In addition, the variety of integrally colored interlayers is now almost limitless. The quality of both of these developments from the past 5 to 10 years have made patterned, colored interlayers a viable alternative to traditional silk-screened ceramic frit for architects and planners to use in their designs.

III Integrated lighting

LED's have been making headway into laminated glass units – mostly as lit signage with incredible effects involving computer controlled changing graphics. The costs here are still quite high running around €1.000 per square meter and the maximum size manufactured is still somewhat limited, but the potential is great and will certainly make advances along with the LED lighting technology development.

IV "Switchable" Opaque/Transparent Panes

A slightly older technology is the liquid crystal interlayer that can be made transparent or opaque by turning it "on" or "off" is still around – again being held back due to its high cost and relatively small formats.

This is an existing recent technology that to date has been affordable for only a few very high class projects. The new developments here are the maximum unit size that is around 1200x3000mm and prices that are getting lower as production quality goes up.

One still sees projects in schematic design stage where architects have included these types of glazing (only to have them dropped later when the costs are defined). It must be remembered, though, that the first cell phone was developed in the mid 70's but the factors of technology and economy did not come together until the mid 90's – here is a product for which demand is there but the technology and economy not yet – I say, wait and it will come.

V Interactive Façade Technologies

This brings up the next logical step in the integration of circuitry in the glass unit where the technology is still quite young and the possibilities great. If the trends continue in a decade or two glass units either as laminated units or IGU's will have electronic circuitry to do a variety of things – sunshading, generating electricity, providing lit changing signage similar to a flat screen TV, interactive such as a glass door that acts as a touch screen to provide secure entry, integrated invisible semi-conductor circuitry that measures heat gain or loss from summer to winter to more exactly control the building systems to increase performance and reduce energy consumption much the same way electronic fuel injection changed automobile engine performance.

These are all, as yet, dreams in the minds of glass engineers.

e. Curving glass

The newest procedure for curving glass is to "cold form" the glass as opposed to heating it and using gravity to let it slump against a mold and recool.

In "cold-formed" glass the characteristic limited flexibility of a pane – usually tempered – is used to force the pane into a curved shape – applicable to single sheets, laminated units or even IGU's – the maximum amount of curve being less than what can be achieved thru heat-curved procedures – the limit determined by the maximum stress the particular pane can take minus the maximum expected loading due to wind, snow, etc. One of the best known recent examples of cold formed IGU's is the IAC building designed by Frank Gehry Architects in New York City where the façade undulates, imitating sails, clouds or whatever white pillowy object that comes to mind.

A variation on the curving method is to cold curve two glass panes together and then laminate them in the curved shape, which takes some of the stress out of the glass and puts it into the interlayer. The expansion of the city of Strasbourg's Main Train Station, done as a part of France's newest TGV high speed rail line, has a large winter garden with a partial toroidal "doughnut" shape done in cold-formed curved glass upon a filigree steel structure.

The recent expanded use of cold formed glazing has been possible due to advance mathematics and the computers that allow economical calculation with credible results, increasing the curvature one dares to do, while lowering the risk of breakage to acceptable levels.

f. Chemical Tempering

An old process that is relatively new to the market is chemically tempered glass. With heat tempered glass the pane is shock cooled, so the outside layer contracts quicker than the inside putting the inside in compression. In chemically tempered glass the pane is soaked in a potassium ion bath which exchanges the sodium ions for the larger potassium ions in the outer layer to create a similar tension/compression balance, though in reverse, with the interior in tension and the exterior in compression. Chemically tempered glass is getting greater attention in architectural applications due to lower tolerances, lesser limits on thicknesses, sizes and shapes especially in curved and/or laminated glazing for example in curved glass railings.

Chemical tempering doesn't have problems with spontaneous breakage and is, in fact, usually stronger than heat tempered glass of the same thickness. Unlike heat tempered panes, a chemically tempered pane can be cut and drilled after tempering, though with a loss of strength in the immediate area of the milling.

Figure 11

Glass bench, courtesy seele

g. Milling of glass

With the advent of CAD-Cam manufacturing at the end of the last century the costs and quality of cutting, drilling, milling glass have considerably improved – the most recent advances have been simply in improving those CAD-Cam machines and building bigger ones to meet the demand for larger and thicker units.

The Apple Flagship Stores with their all glass stairs have been a major force in developments in glass milling as Steve Jobs himself demands the same quality on the glass edges that he does for Apple products. A typical glass tread is a four-layer approx. 50mm thick, laminated float glass unit that is edge polished up to 8 times to crystal glass quality.

5. Cast glass

Seattle, Washington is a center of glass industry for blown and cast glass – second only to Venice's Murano Island. Here there are glass manufacturers developing new kinds of cast glass for all kinds of uses. Unfortunately, the general use of cast glass in buildings is yet to come, as the costs are still higher than the market would like.

6. Innovative uses

a. Glass bridges

Since the introduction of polycarbonate interlayers around 10 years ago, the use of glass as a structural element has exponentially increased – the non-plus –ultra being the execution of all glass bridges of ever increasing spans and decreasing glass weight. The latest of these wonders was seen in Düsseldorf at Glastech last October where the glass façade design-build contractor exhibited an arched glass bridge out of a composite "U"-shaped glass beam consisting of a curved laminated glass floor with attached glass beams that doubled as bridge railings.

Up until this creation glass bridges consisted of glass railing beams with the glass floor suspended between them – which is pretty amazing in itself. These bridge constructions all have the inherent redundancy of a polycarbonate interlayer that, in the case of massive glass breakage (no pane remains whole), the bridge still supports its designated live load – although in a sagging geometry more like a rope bridge.

b. Glass benches

There are a couple examples of glass used structurally for the simple act of sitting – some using cast glass blocks, either in the same manor as masonry such as what Kaindl Art Cast Glass in Seattle Washington has done for a Manhatten street park or in the case of a cantilevered bench from Seele in Germany with a steel foot and vertical milled sliced of glass held together like a loaf of sandwich bread with post tensioning rods – using the impressive compression strength that glass has.

c. Glass radiators

Saint-Gobain has developed a pane of laminated glass with a transparent, electrified interlayer that radiates heat and can be used as a radiator in any location that a pane of glass could be used. One of the best ideas is a towel rack out of this heating glass shelving so the bath towels can be warmed up. If the glass radiator gets a silver coating it can be used as a mirror – one that not only doesn't fog up but also heats the whole bathroom. With a bit of creativity, the use of heating glass units will certainly not be relegated only to the bathroom.

7. Glass supports

a. *Aluminium extrusions*

The manufacture of aluminum extrusions for use as mullions has advanced enough that the cost of cutting new dies for different mullion shapes is low enough to allow a single facade to have multiple mullion shapes and still be fairly affordable. This has allowed architects and planners today to be freer with a building's geometry – a result of modern CAD-Cam manufacturing – the same development that has made drawing up the plans for such complex geometries easier and more exact.

b. Gridded shell structures

CAD and CAD-CAM have made irregular building shapes technically (thru higher tolerances) and economically (thru ease of drawing and manufacturing) possible. This has opened up the use of geometries that are fully or partially self-supporting in the manner that a shell structure is stiff due to its 3D geometry.

This was most spectacularly achieved at the Milan Convention Center by Massimiliano e Doriana Fuksas Architects with an undulating glazed triangular gridded roof. No two pieces of glass have the same geometry – something achievable only thru the use of computers during the design, fabrication and even the delivery (logistics programs). This has opened up a whole new field of architectural possibilities and there are many such projects currently in the works.

c. Point supports

Traditionally point supports for glazing have been similar to those for any other material – drill a hole and put a bolt thru it. With glass it has to be done carefully to not overstress the material with high point tension loads – a tricky undertaking considering the low maximum allowable stresses – but designers and the industry are getting good at doing this and the size and number of point supports have been going down slightly while at the same time increasing in the quantity of projects where they are used.

d. Bonded supports

A new kind of bonded point support is invading the market – one that evades the inherent conceptual problem of drilling a hole in the glass, essentially 'wounding it' and then putting the maximum stress, by addition of a bolt, at that 'wound'. When connections are bonded, there is no hole and the size of the bond can be tailored to the structural calculations, spreading the load and reducing the maximum stresses – the point connection follows the load diagram.

In fact, if the load is a linear one, the connections are not a line of point connections, but rather a continuous line, reducing, for example, the size of a connector plate on a glass fin by well more than half, making the connection look smaller and more elegant.

Bonded connections are being made possible thru new adhesives coupled with long term testing by specialty façade manufacturers/contractors. Here the weak point is the possible break down of the bond over time – moisture being the main enemy. A well engineered bonded joint should, however, have no disadvantages over a classic point connection.

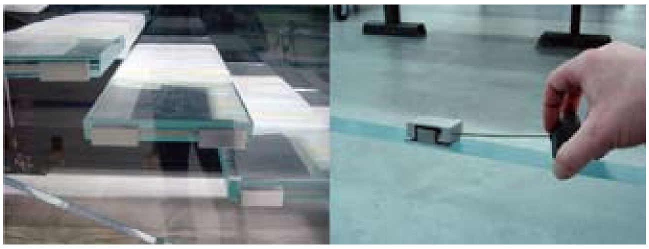
8. Glass formats

Market demand in the form of architects and building clients wanting ever bigger, more spectacular sizes of façade units has led to a movement in the industry to ever bigger processing equipment.

a. Size of panes

What this means is that oversize panes are becoming more and more prevalent. The maximum width of approx. 3.1 to 3.2 meters, due to the standard maximum width of float glass manufacturing will probably remain, but lengths of single pieces of glass up to 12m (which can still fit into an oversize shipping container) are becoming more common. These maximum sizes are however being challenged in laminating units by creating what is in essence a type of "plywood" glass made out of smaller glass sheets bonded together using polycarbonate interlayers. In this manner glazing units of around 13.5 meters in length were fabricated for the Apple Flagship Store in Sydney, Australia. Up to 15 meter lengths of laminated glass are currently possible. The width of 3.2 meters still has to be broken as this requires a laminating autoclave with a diameter of more than 3.2 meters, but it may only be a matter of time before it comes – the technology and know-how certainly exists. However, to put this in perspective, it must be remembered that pre-float-process plate glass easily surpassed the 3.2m width, as can be seen in windows from the 1950's that show off copper kettles at the breweries in Munich (such glazing no longer is allowed). It must also be said that the current financial crisis may put a damper on this development as the demand for larger sizes – which cost more – will most likely decrease – though one advantage is that the research and development departments at glass manufacturers now have the time (and incentive) to develop new methods and products.

Figure 12
Bonded instead of bolted glass tread connection (courtesy seele)



b. Size of insulating units

Here the industry has reached a maximum in that an insulating unit with the normal maximum size of pane of float glass, 3.15m x 12m, is possible (though not inexpensive) so that the limit now is more an economical one. If laminated glass is used, then theoretically an insulating unit of 3.15m x 15m by splicing smaller panes together may be possible (again this equals the largest size autoclave for laminating glass). Here we can conclude that it is no longer a technical problem to meet the designer's needs and the market's demands for oversize IGU's, but rather an economical one.

c. Thickness of units

Thru improvements on existing manufacturing processes, laminating technology has been delivering ever thicker pieces of laminated glass. The current limit is somewhere around 10 to 12 panes of glass in thickness or around 100mm to 150mm thick – the size of the unit possible based on the size of the autoclave available and the daring of the manufacturer. Such efforts to push the limits of manufacturing and technology are always coupled with a lot of glass breakage – the usual price for advancement in the glazing industry.

9. Blast resistant glazing

With the advent of terrorist bombings, most likely happening at fully glazed daylit lobby entrances of important public and private buildings, the demand for blast resistant glazing is on the rise. One of the most significant projects regarding this is the World Trade Center 7 building completed in 2006 and designed by architects, Skidmore Owings and Merrill LLP, where, with James Carpenter's expertise a blast resistant point held, cable net façade was executed. Laminated glass, with either PVB or polycarbonate interlayers (depending on the blast load) provides the necessary protection against splinter throw and often structural silicon glazing, due to its stiff characteristics under extremely large millisecond dynamic loading, offers an almost perfect blast resistant hold against glass unit failure. Structural silicon can also provide the necessary hold in normal aluminium or steel mullion façade systems with capped or point held glazing.

A couple current projects where large blast resistant glass walls are planned or under construction are:

- the World Trade Center PATH Station and the nearby Fulton Street Subway Station in New York City
- the US Institute of Peace on the Washington D.C. Mall

We will certainly see more of blast resistant glazing systems – there is much development potential here – though again the economics may determine the direction.

An attempt was made to do a blast resistant cable wall for the new Federal Court House in Cedar Rapids, Iowa, designed by OPN Architects was eventually dropped due to economical considerations.

10. Hurricane resistant glazing

Related to blast resistance is the advent of hurricane resistant glazing – the demand being mostly in the southeast United States where Caribbean generated hurricanes over the last few years have been taking their toll on buildings and where building codes since 5 or 6 years now require such glazing on new construction. The Florida Code for hurricane proof glazing, which has become the inofficial standard for other areas, requires shooting a 2x4inch wood stud out of an air cannon at the laminated pane and then wind pressure cycling the pane back and forth, requiring that it stay intact. Owners are also demanding this type of high impact resistant enclosure, if their building has valuable contents – such mainframe computer systems or original artwork, both usually worth millions, easily justifying the extra expense. Here the combined use of laminated glazing with impact resistant polycarbonate interlayers and structural silicon bonding to appropriately sized steel frames allow enough flexibility in size and costs to meet just about any aesthetic and economic demands.

11. "Looking thru the Looking Glass"

What are the trends in architectural glass today?

The answer is multi-varied but is based on a few main directions:

- new more transparent architecture as well as more complicated geometries – driven by a definite aesthetic movement among architects, planers, designers and building clients
- new uses for glass, in particular as structural elements – made capable thru new engineering capabilities such

as reliable calculations and testing for structural use of glass, etc.

- demand (and necessity) for more efficient building enclosures - whether for energy conservation, blast resistance, reduction of structural supports, etc.
- new technological directions in fabrication – driven by new processes as well as more exact tolerance in processes, such as for coatings, milling, laminating, bonding, etc., but also for the need for new products such as energy generation within the building enclosure (solar cells, etc.).
- Hopefully this here gives a good overall view of these directions and where they might end up – but experience tells us that glass is hard to predict and who knows where and how we may end up using glass in the future – but we know the prospects are exciting.