An Overview Of Glazing Systems

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INTRODUCTION

This paper is a summery of an undergraduate report prepared by the author as the major study of the elective subject Lightweight Structural Design which forms part of the Bachelor of Architecture program at the University of New South Wales. The report was submitted in November 1995, under the direction of Associate Professor Vinzenz Sedlak.

The principle goals and objectives of the study into glazed lightweight structures were as follows;

- to inquire into glazed lightweight structures in order to gain an understanding of the architectural and structural aspects of such structures.
- to contribute to the body of knowledge existing on types of lightweight structures.

The report was divided into four main sections;

- the first dealt with design considerations
- the second detailed different types of glazed lightweight structures
- the third section was a survey of 23 recent australian and international glazed lightweight structures. The survey was formatted to correspond with the Lightweight Structures in Architecture and Engineering Database (LSAE) complied by the Lightweight Structures Research Unit (LSRU).
- The final section was a concluding section drawing together the major findings of the study

In order to concentrate on lightweight structures, structural silicone glazing and traditional glazed curtain wall structures were not be considered within the report. All glass structures, although not purely lightweight structures, were considered as they represented recent advances in glass and structural technology and their translucent appearance causes them to appear to be lightweight structures.

DESIGN CONSIDERATIONS

The report firstly examined a number of considerations that should be taken into account when designing glazed lightweight structures. These considerations are as follows; The physical properties of glass, Glass types, Structural considerations and Other considerations such as environmental control, maintenance and controlling regulations

THE PHYSICAL PROPERTIES OF GLASS

Glass has a large number of physical properties that are responsible for the unique way it behaves, for example the way in which allows the transmission of heat and light. However, there are a number of these properties that are of particular relevance when designing glazed lightweight structures. The first of these physical properties stem from the nature of glass, which is neither a liquid nor a solid but a liquid that has been cooled to a solid state while retaining a random atomic structure.(Upshall 1989 p.386) The atomic structure of glass is unable to allow any plastic deformation and so when glass is overstressed, the atomic bonds fail and the glass breaks. Consequently, point loads and stress concentrations are common causes of glass breakage. Glass, however, is able to deform elastically and provided that it is not overstressed, glass returns to its previous shape once the load is removed. Glass also does not suffer from dynamic fatigue and can be stressed many times and always returns to its previous shape.(Button & Pye 1993 pp.211–227).

Glass is potentially a strong material, in theory having both a high tensile and compressive strength. However, the presence of small flaws, known as Griffiths flaws, in the surface and edges of the glass, make it susceptible to failure at a much lower stress than its theoretical strength would suggest. (Button & Pye pp.212–214) These small flaws are caused by particles of dust and moisture vapour in the surface of the glass as well as by the cutting and edge finishing of glass. (Button & Pye pp.213–216)

Glass is also subject to failure due to thermal stress (Grusauskas 1991 p. 9) These stresses are created when one section of a piece of glass absorbs heat and expands and meets an area of glass that has not been heated to the same degree. This expansion is resisted by the cooler section of glass and if the stress that is generated is high enough, failure of the glass can occur. (Button & Pye p.245)

GLASS TYPES

Within the realm of glazed lightweight structures there are three main types of glass that are commonly used. These are; heat strengthened, toughened and laminated. The first two types of glass, heat strengthened and toughened, involve heating and rapidly cooling sheet glass to produce a product that has a greater strength than ordinary glass. Toughened glass is up to five times as strong as normal glass in bending while heat strengthened glass is approximately twice as strong. (Grusauskas 1991 p. 12) Both glass types also have an increased resistance to thermal stress with toughened glass again being the strongest. The higher degree of surface compression in toughened glass results in its breaking into small pieces if it fails.(Button & Pye pp.21–29) Heat strengthened glass retains much the same shattering characteristics as normal glass. The increased level of surface compression makes it impossible to cut or drill both types of glass once they have been heat treated and so all such work must take place prior to heat treating. (Rice & Dutton p. 34) Toughened glass has one other potential problem in that it can spontaneously shatter due to nickel sulfide inclusions in the glass. (Carfrae 1994 p.78) This risk of shattering can be reduced by heat soaking. (Rice & Dutton p. 100 & Rumbel p.90)

The other type of glass commonly used in glazed lightweight structures is laminated glass. As the name suggests this involves the joining of two or more layers of glass together with an intermediate layer of resin or plastic. The reasons for doing this are several; it enables greater thicknesses of glass to be produced than is normally possible, the intermediate layer can hold the glass splitters in place if one or more of the glass layers breaks and special properties such as fire resistance can be added to the intermediate layer to improve the overall functioning of the glass. (Button & Pye pp.240–241) Ordinary annealed float glass can be used in laminated glass as well as the heat treated types. (Grusauskas p.12)

Various surface treatments can be added to all these types of glass to improve or change characteristics such as reflectivity and colour. Each glass type can also be combined to form double and triple glazing units, which have superior sound and thermal insulating properties. Various gasses can be introduced into the gap between the sheets of glass to further improve their acoustic and thermal performance. (Button & Pye pp.153–176)

STRUCTURAL CONSIDERATIONS

Apart from the usual structural considerations that form the basis of all structural design, the design of glazed lightweight structures have their own set of specific considerations. The first consideration is the types of loads able to accommodated by glass. As previously mentioned, glass is able to cope with uniform loads up to a certain level while not responding well to point loads and stress concentrations. (Walker 1991 pp.23–26) Therefore glass is usually only structurally exposed to wind, suction and snow loads.

The second consideration is the method by which it is proposed to support the glass. There are three basic support methods; four sided, two sided and point fixing. Four sided support has the advantage that it able to use glass that is half the thickness of two sided support because of the dome like deflection generated by uniformly loaded four sided supported glass. Two sided supported glazing deflects by bending only and needs to be thicker to prevent failure stresses from being reached. (Carfrae p.77) Point fixing is usually placed in the corners of the glazing and the sheet also deflects into a dome–like shape under uniform load, however the point fixing causes concentration of stresses and the glass should not be allowed to reach the same level of deflection as in four sided support. (Rumbel p.90)

Thirdly, the thermal movement of glass must be taken into consideration to prevent stress concentrations from occurring. This movement can be accommodated by a variety of different methods, however, all of them allow the glass to expand and contract to some degree. Likewise, detail design of elements of the structural system must also prevent thermal stresses from overstressing the glass.

Although glazed lightweight structures appear as if they are lightweight, glass is a heavy material, having a density only one third that of steel.(John Lysaght Australia Ltd. 1988 p.276) This relatively high density when combined with the large areas and thickness of glass required for such structures can lead to large dead loads being generated.

The final consideration is that the structural supporting system must be able to cope with any failure of all or part of the glazing. This failure can be due to overstressing or point loading, however the remainder of the system should remain intact and not lead to the failure of other glass panels through load imbalances.(Rumbel p.90) The use of safety glass such as toughened and laminated glass is only part of the solution to glass failure.

OTHER CONSIDERATIONS

The issues of heat gain and heat loss are important considerations that must be taken into account especially in Australia's climate and in light of the current environmental concerns. The design of the glazed structure should also address the issue of whether external noise is a concern. If it is, multiple glazed units can also be used to reduce sound intrusion.

As the one of the main purposes of having large areas of glazing is to take advantage of the transparency offered by glass it is important that the glass surface is able to be periodically cleaned.(Rumbel p.91) It is not always possible to have a team of trained mountain climbers on hand for window cleaning duties as in the case of the glass pyramid at the Louvre Museum in Paris.

Other considerations include; Glass replacement – the structural system must allow for the replacement of sections of glass from time to time, Regulations – the various regulations and standards governing the use and design of glazing must always be considered. These include the requirements of the Building Code of Australia, particularly clauses B1.2, B1.3 and C3.4 and Australian Standards; AS 1288 – Glass in buildings – Selection and Installation, AS 1170 – Minimum design loads on structures (SAA Loading Code) – Parts 1,2 & 3 and AS 2208 – Safety glazing materials for use in buildings (Human impacts considerations). (Grusauskas p.10 & Walker pp.23–28.)

TYPES OF GLAZED LIGHTWEIGHT STRUCTURES

The report then examined the various types of glazed lightweight structures currently in existence throughout the world. The structures were categorised in accordance with their structural support into the following groups;

- glass mullion systems
- all glass systems
- planar systems
- articulated bolt system
- framed systems

- space grid systems
- cable net systems

GLASS MULLION SYSTEMS

The glass mullion systems utilise the inherent structural stability of the surrounding structure. In these systems the glass is suspended from the main structure of the building and lateral support is provided by large glass mullions placed immediately behind the plane of the glass cladding. In the Pilkington suspended system metal patches are used to attach the panes of glass together as well as to the glass mullions.(Button & Pye pp.329–332.) Considerable concentrated stresses are generated by the patch fittings and as a consequence the emphasis of the structural system is to reduce deflections and to reduce the stress concentrations at the patch fittings.(Dutton & Rice pp.44–45) These systems almost always use toughened glass to take advantage of its inherent strength. At the junction of the glass and the floor and adjoining walls, glazing channels are used to provide stability while allowing thermal expansion of the glass. The junctions of the glazing are sealed with silicon sealant. These systems can only be used in vertical situations and are only able to use single layers of glass.(Button & Pye pp.329–332.) An example of this type of glazed lightweight structure is;

- Willis Faber Dumas Building – Ipswich, UK (1975)

ALL GLASS SYSTEMS

The recent development of all glass structures appear to follow on from the previous type of glazed lightweight structures. In these systems glass is used as the primary structural support elements as well as the cladding material. Most of these structures have been built as extensions to existing buildings and are only glazed on two sides as well as the roof.(McGuire 1995 pp.24–27 & McGuire 1993 pp.67–70) Structurally these structures utilise the post and beam structural system with laminated toughened glass being used to form both the post and beams. Structural silicon is used to join the posts to the beams as well as the laminated glass cladding to the posts and beams. The structural stability of these structures is aided by the existing buildings onto which these structures have been added. Lateral stability is achieved through shear plane action of the glass cladding as well as through attachment of the structure to the existing building.(Addis 1994 pp.120–121) Thermal expansion is catered for in the flexibility of the silicon sealant. Examples of this type of glazed lightweight structure are;

- House extension – Hampstead, London, UK (1992)
- Museum of Glass – Kingswinford, West Midlands, UK (1995)

PLANAR SYSTEMS

The planar system, developed by Pilkington Glass in the 1980’s, has been used to produce a large number of glazed lightweight structures. The basis of this system is the countersunk patch fixing of the glass panels and the individual supporting of each glass panel. The load of each sheet of glass is first supported by the countersunk patch fixing and then through the main supporting structure.(Button & Pye pp.332–341) Uniform loads cause deflection of individual glass panels, resistance to which is provided by the supporting structure. Stress concentrations at the patch fittings are reduced by the introduction of a flexible plate that allows the whole panel of glass to deflect, reducing problems associated with the tight clamping of glass found in traditional patch fittings.(Rice & Dutton p.36) The supporting system can be made up of a variety of elements such as horizontal and/or vertical trusses. It is also possible with this system to reduce the supporting structure to a network of thin, highly pretensioned steel rods or cables with relatively small compression members. This network provides resistance to inward and outward uniform loads as well as supporting the dead load of the glass. In all the different methods of providing structural support it is important that all the stresses are accurately predicted especially at the countersunk patch fittings to avoid overstressing of the glass.(Button & Pye pp.332–341) Lateral stability is usually provided either by the main structure of the building or through bracing of the supporting structure. The glass panels are joined with silicon sealant that provides a weatherproof seal and the whole system allows thermal movement of the glass. The system is able to be used for vertical, sloping as well as horizontal situations. Double glazed units are also able to be used as the countersunk patch fittings only require that the outer sheet of glass is supported. This allows the insulating air space to be retained. Examples of this type of glazed lightweight structure are;

- Supreme Court of the Council of Europe – Strasbourg, France (1994)
- Long Term Credit Bank – South Atrium– Tokyo, Japan (1993)
- Western Morning News – Plymouth, UK (1992)

ARTICULATED BOLT SYSTEMS

The articulated bolt system was developed by Peter Rice of Ove Arup & Partners / RFR (Paris). (Carfrae 1991 p.51) It is based on the planar system but differs from it in a number of ways. The first main difference is that the glass is used as part of the supporting structure. Typically, banks of glass sheets are suspended vertically from a main supporting structure via a series of countersunk patch fittings. The uppermost glass panels are connected to the main structure by a series of suspension type and countersunk patch fittings which transfer the dead load and part of the uniform loads to the main structure. The suspension fittings also allow the system to cope with failure of a sheet of glass by reducing any shock and distributing the load to other surrounding glass sheets.(Rice & Dutton pp.43–61) The glass can also used to provide some of the lateral support to the overall structure provided that the stresses are kept within the plane of the glass. Resistance to inward and outward uniform loads is provided by a series of vertical cable trusses and by the main structure. Connection to the glass panels is via the same countersunk patch fittings used to vertically support the glass. The cable trusses are highly pretensioned to provide sufficient resistance to the uniform loads. The large amounts of pretensioning required in the tension members requires that strong anchorage points are provided.(Rice & Dutton pp.62–75)

The second main difference is in the fixing method, from which the name of the system originates. Ball bearing sockets are introduced into the countersunk patch fitting. These ball bearing sockets allow the glass to deflect without the glass being restrained at the fixing point and so reducing stress concentrations.(Rice & Dutton p.37) As with all glazed structures this systems requires that all the stresses are accurately predicted and catered for. Silicone sealant is used to join and weatherproof the glass panels. The system is primarily used in vertical situations because of the use of the glass to provide vertical support. Variations of this system have however, been used in horizontal situations.(Carfrae 1994 pp82–83) Examples of this type of glazed lightweight structure are;

- Atrium de L’Immeuble 50, Avenue Montaigne– Paris, France (1993)
- Long Term Credit Bank – North Atrium– Tokyo, Japan (1993)

FRAMED SYSTEMS

The use of framed systems to support glass is perhaps the oldest method of supporting glass. However, recent advances in lightweight structures have been used to provide support to the framing, resulting in the construction of large span glazed structures. Glass is usually supported within the frame on either two or four sides. As previously mentioned, four sided support allows thinner sheets of glass to be used.(Carfrae p.77) The use of framing has the advantage that the glass is held continuously along its supported edges reducing the likelihood of the development of stress concentrations. Allowance for thermal expansion is usually catered for by the use of silicon sealant in glass to frame and glass to glass connections. The sealant is also used for weatherproofing. The framing can also be used as part of the structural system, resulting in a decrease in the amount of supporting structure required and increasing the apparent ”lightness” of the structure.(Carfrae p.86–87) Although the supporting structure can take many forms, truss based systems are predominantly used because of their great spanning capabilities and the relatively small size of their members.(Schodek pp.439–440) Framed systems can be used in horizontal, sloping and vertical situations. In vertical situations, the glazing can be placed on either side of the supporting system as well as in between it. Examples of this type of glazed lightweight structure are;

- Transport Interchange – Chur, Switzerland (1992)
- Kansai International Airport – Glazed End Walls – Kansai, Japan (1993)

SPACE GRID SYSTEMS

The long span capabilities of space grids as well as their inherent rigidity make them a suitable supporting structure for glass. The ”lightness” of their component members also compliment the apparent ”lightness” of the glass. Some of the planar systems are very close to being space grid or truss systems because of the interconnected network of trusses that are developed to support the glazing. In space grid systems the glass performs only a cladding role and is only required to cope with the deflections caused by wind and suction loads. The rigidity of the space frame allows the use of surface patch fittings as well as patch fittings.(Bersten 1994 pp.64–67) Examples of this type of glazed lightweight structure are;

- Zenith Centre – Chatswood, Sydney, Australia
- Jacob Javits Convention Centre, New York, USA

CABLE NET SYSTEMS

Recently cable net support structures have been adapted for use with glass to produce long span, glazed lightweight structures. As cable net structures use relatively thin cables, the addition of glass leads to the creation of structures that are extremely ”lightweight” in appearance. Two systems that have been recently used are a flat wall system and a curved roof system.

The flat wall system uses a single plane grid of highly pretensioned steel cables arranged at a spacing of about 1.5m. The cables are clamped together at the intersection points with fixing clamps. The glass is attached to the grid at each corner by the use of a fixing clamp that is integrated with the cable fixing clamp. The horizontal and vertical joins between glass panels are sealed with silicon sealant. As the whole surface of the wall deflects under wind and suction loads, the deflection of individual panels of glass is limited. This ensures that there is only a small concentration of stress in the glass at the clamping points. The high degree of pretension in the cables, upon which this system relies for its stability, requires that a sufficiently strong perimeter support structure is available onto which the cables can be anchored. (Schlaich & Wagner 1995 p. 731)

The glazed curved roof system uses a cable stiffened shell grid as the supporting structure to produce a single curve vault roof. (Schlaich & Schober 1994 pp. 16–24.) The system involves the use of a square grid of metal bars curved to form the circular vault shape and stiffened by an interconnected diagonal grid of pretensioned cables. The metal bars and cables are fixed together at the junction points of the metal bar grid. The metal bars are also used to hold the glass panels in place and provide four sided support to the glass. The structure can be stiffened by the use of ”spokes wheels” which add tension to the cables in the grid. (Schlaich & Wagner 1995 p. 731.) It is also possible to create glazed domes using a similar construction technique although the panes of glass have to cut into varying rhomboid shapes to accommodate the double curve of the roof surface. (Schlaich & Schober 1994 pp. 4–6) One of the leaders in the field of glazed cable net structures is the German firm of structural engineers, Schlaich Bergermann & Partners, Stuttgart. They were responsible for the structural design of the two following examples;

- Hotel Kempinski – Munich Airport, Germany
- Museum of History, Hamburg, Germany

RECENT AUSTRALIAN AND INTERNATIONAL GLAZED LIGHTWEIGHT STRUCTURES

The third section was a survey of 23 recent Australian and international glazed lightweight structures. The survey was formatted to correspond with the Lightweight Structures in

Architecture and Engineering Database (LSAE) by the Lightweight Structures Research Unit at the University of New South Wales. The following glazed lightweight structures were included in the survey:

House extension – London	UK	1992	All Glass System
Museum of Glass – West Midlands	UK	1995	All Glass System
Car Showroom – Hamburg	Germany	1993	Planar System
Office Building – London	UK	1993	Planar System
Supreme Court of the Council of Europe	France	1994	Planar System
TGV– Roissy Airport – Glazed Walls	France	1994	Planar System
Waterloo International Terminal – Screen Wall	UK	1993	Planar System
Atrium de L'Immeuble 50, Avenue Montaigne	France	1993	Articulated Bolt System
Channel 4 Television Studios – London	UK	1994	Articulated Bolt System
Governor Phillip Tower – Atrium Roof	Australia	1994	Framed/Articulated Bolt
Governor Phillip Tower – Atrium Walls	Australia	1994	Articulated Bolt System
Long Term Credit Bank– North Atrium	Japan	1993	Articulated Bolt System
Administration Building – Paris	France	1992	Framed System
Brisbane Convention & Exhibition Centre	Australia	1995	Framed System
Kabuki–Cho Tower – Tokyo	Japan	1993	Framed System
Kansai Airport – Glazed Walls	Japan	1993	Framed System
Long Term Credit Bank– South Atrium	Japan	1993	Framed System
Robert Clark Horticultural Centre	Australia	1995	Framed System
TGV– Roissy Airport – Glazed Roof	France	1994	Framed System
Transport Interchange – Chur	Switz.	1992	Framed System
Waterloo International Terminal – Roof	UK	1993	Framed System
Zenith Centre – Atrium	Australia	1988	Space Grid System
Hotel Kempinski – Munich	Germany	1994	Cable Net System

CONCLUSION

There are a variety of different methods of providing structural support to glass cladding. While all of the various systems have their own inherent benefits and drawbacks, it is possible to come to a number of overall conclusions regarding issues such as lightness of structure, span capabilities and environmental control.

The first conclusion was that although all glass structures at first appear to be the most ”lightweight” of all the structural systems, the reality is that the support structure is probably the heaviest in terms of span to weight ratio. The thick (30mm) columns and beams required to support the cladding also interfere with the transparency of the structure, especially when it is viewed obliquely. Cable net structures, on the other hand, appear to offer the most lightweight support system, both visually and structurally, of all the systems examined. The glazed atrium wall of the Hotel Kempinski, Munich is an excellent demonstration of the lightness of the cable net system. The only apparent structure is the grid of fine cables and node fittings that clamp the cables and secure the glass. When viewed from a distance the grid disappears, leaving a clear view through the atrium. The value of this system is not just reliant upon its visual lightweight qualities but also in its simplicity and ease of construction. The deflection of the whole wall surface reduces the risk of stress concentration in the glass while the use of only three major components, cable, glass and clamp, makes for a very straightforward construction system. The only potential drawback to this system is the requirement for a strong perimeter support structure onto which the highly tensioned cables can be secured.

The remainder of the systems offer varying degrees of ”lightness”, with their real worth, in visual terms, being the architectural character that is developed through the expression of the structural support system. Systems such as the planar, articulated bolt and frame systems also offer the ability to combine the glazing support structure with other support systems in a building to achieve a more integrated structural solution. The car showroom, Hamburg and the roof of the

Waterloo International Terminal, London are examples of this type of glazing support and overall structure integration.

Four entries are included as examples of the database:

Figure No.1
All glass extension, Hampstead, London
Source: McGuire P.. (1993), Heart of Glass, In The Architectural Review, No. 1152 Feb. 1993 p.69.

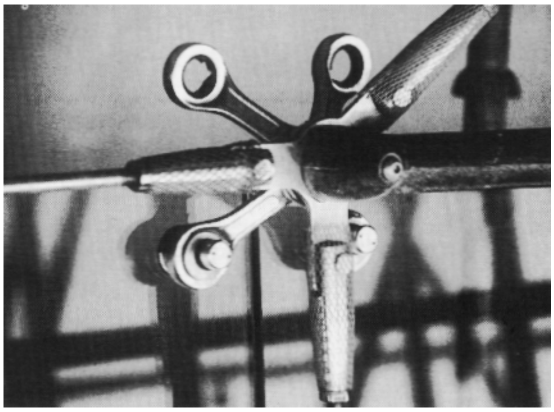

Figure No.2
Detail of planar fixing – Western Morning News
Source: Davey P. (Ed.) (1993), Products Survey , In The Architectural Review, No.1154, April, 1993, p.94.

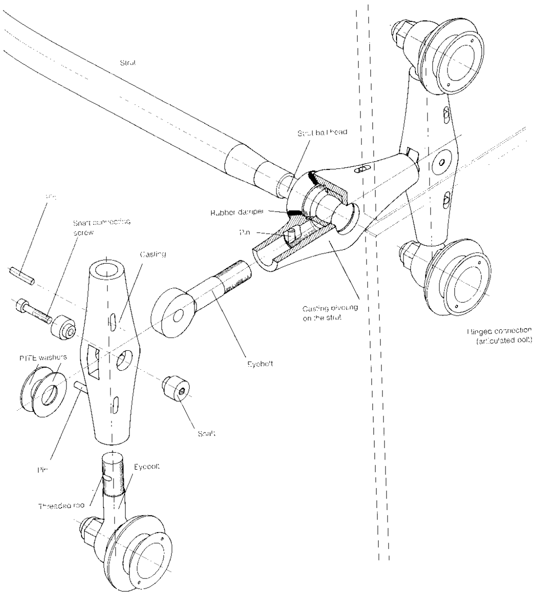

Figure No.3

Exploded axonometric of articulated bolt fixing patches

Source: Rice P. & Dutton H. (1995), Le Verre Structurel, Moniteur, Paris, p.63.

Figure No.4

View of framed glazing with bowstring trusses – Kansai Airport

Source: Buchanan P (1994) Kansai, In The Architectural Review, No. 1173 Nov, 1994. p 78

The second major conclusion that can be drawn from this study is in regard to the spanning capability of the various support systems. Framed systems when used in conjunction with trusses offer one of the largest span capability of all the systems. This is evident from glazed truss roofs of the Chur Transport Interchange and Waterloo International Terminal where clear spans of approximately 50 metres have been achieved. Space grid support structures also offer the ability to create large spans, although the only example found for this study, the Zenith Centre, only had a span of approximately 25 metres. However such structures are capable of much larger spans as witnessed by the Jacob Javits Convention Centre, New York.

If the amount of support structure to span is taken into consideration the cable net system offer the best performance with a horizontal span of approximately 40 metres being achieved in the facade of the Hotel Kempinski. Systems such as the planar and articulated bolt systems also offer relatively large spans when the support structure is formed into a framed grid type structure or a perimeter support structure is available to support the glazing support system. One such example is the span of approximately 24 metres achieved in the Atrium de L'Immeuble 50, Avenue Montaigne, Paris. The worst span performance of all the structural support systems is the all glass system where traditional column and beam construction and the physical properties of glass limit the clear span to 1.1 metres and this is only achieved by the use of large, thick glass structural members.

Thirdly, as the concentration of stress in glass can lead to its failure, the method of holding the glass cladding in place is an important consideration in the selection of structural support system. Obviously systems that provide two and four sided support to glazing offer the highest degree of inherent support and therefore resistance to glass failure. Examples of this type of fixing are framed and cable net shell grid structural systems. However this comes at the expense of the transparency of the whole system. The articulated bolt system, with its ability to pivot and avoid the concentration of stress at the fixing point is probably the next most preferable system. Corner clamped fixing systems such the planar and glass mullion systems are the least advantageous and require an extremely stiff supporting structure. Although the nature of the deflection in the single plane cable net systems counteract the problems that can be created by corner clamping.

Fourthly, while the focus of this report has been on documenting the various different types of structural support systems currently being used, some mention should be made of the issue of environmental control. Many of the examples in this report are found in locations with long cold winters and short mild summers. Large areas of glazing have the advantage that they are able produce a protected indoor environment that allows the transmission of sunlight while screening the worst of the winter weather. While heat gain during summer can be a problem it can be overcome by the use of non–mechanical convection cooling and high ceilings. In such climates, heat loss is more of a concern, witnessed by the widespread use of double glazing and Low–E glass. In contrast, Australian summer conditions are far harsher and more effort is placed on reducing heat gain rather than heat loss. The hotter climate also results in a desire to seek relief from the summer sun and heat. Consequently, lightweight glazed structures in Australia are more modest in scale, located in positions where they are shaded by other structures or are isolated from the other parts of the building to limit the spread of captured heat. Although it is possible to combat heat build up by mechanical means, the prevailing mood of society and construction professionals is to limit the reliance on air conditioning and so reduce environmental pollution. Other means of reducing heat gain such as reflective coatings have the disadvantage that they decrease the transparency of glass. Consequently, the construction of large glazed lightweight structures in Australia should remain limited until other environmentally and visually acceptable methods of reducing heat gain are developed.

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