

# Construction of All-glass Structures with External Glass Frames

Philip Wilson, Gennady Vasilchenko-Malishev  
Malishev Wilson Engineers, 96a Inderwick Road, London N8 9JY, UK  
info@malishevwilson.com

## Keywords

1=All-Glass

2=Structure

3=Beams

4=Fins

## Abstract

The construction of two all-glass structures with external glass frames marks an important milestone in glass engineering and fabrication. While supporting the structure from the outside, glass is naturally resistant to corrosion and weathering.

The first structure, comprises twin, single piece, external 6.9m long glass beams linking two parts of a Grade II listed domestic dwelling designed by Erno Goldfinger in 1966. Internal volume is 7.6m long, 5.5m wide and 2.6m high. External glass frames give a clear, unrestricted internal space where the roof level has to align with the existing low-level buildings as a planning condition. The moment-resisting glass frames required analysis of compression flange buckling of the glass beams and led to an innovative fin-to-beam connection detail that visually corresponds with the original architecture. Load transfer is achieved through bearing in holes with development in design and fabrication method since the first application for the Yurakucho canopy for the Tokyo International Forum in 1996.

A second glass structure is smaller in size but more sculptural, with steep upward sloping external glass beams and glass fins that project out from the roof terrace. The base connection of the glass fins is set away from the existing wall structure to give a glass floor panel that floats out over the space below. For both projects, all wall and roof units were treated with high performance 'soft' coated, double-glazed units to reduce solar gain, which looks set to become standard for all-glass structures with high levels of sun exposure.

## Introduction

In the last decade, we have seen a dramatic increase in the use of structural glass in buildings, due to increasing interest from architects. The obvious reason to choose glass is because it is a transparent yet durable material, resistant to weathering. By using supporting glass structures and frames, like beams and fins, this increases the transparency even further.

Traditionally, glass beams and fins have been located on the inside of glass enclosures, so that the glass roof panels would prevent the compression web from buckling and also to protect the beams from the weather. These types of structure have been built extensively for the last 10 years and have proved to be robust and durable.

Working on one of our projects outside London, a glass conservatory at 'Teesdale' in Surrey, we came across one simple problem - that of headroom. Due to the specific geometry of the conservatory, the beam depths needed here were quite substantial. As the overall height of the existing building was quite small, the option of having beams inside the conservatory was self eliminating. The obvious choice, therefore, was to put them on the outside, which leaves the entire internal space free of obstructions.

## Concept of 'Universal space'

The glass conservatory underlines the concept of 'universal space', originally proposed by Mies van der Rohe, where by putting the structure on the outside, space undivided by structural elements could be created. Crown Hall, at the Illinois Institute of Technology (IIT) building in the USA is one example of this.



Figure 1  
Crown Hall, at the Illinois Institute of Technology (IIT)

An obvious advantage of 'universal space' is the increased heights and depths of the internal space, with no obstructions from fins. In addition, external vertical fins help to form the door frame, which is frequently a problem for glass conservatories.

The disadvantages of the external beams and fins would be:

- Increased potential for buckling of the element as the web is in compression and is no longer restrained by the roof panels.
- A greater chance of delamination occurring in the element when subject to weather exposure.
- Cold bridge problems: a thermal break is necessary.
- Increased length of the structural glass elements, creating manufacturing challenges
- Snow drifting and additional wind load.

## Structural design of glass structures

Glass is an inert material and naturally resistant to climatic weathering. However, when used as a structural element, glass being a brittle material, fails abruptly without first yielding or permanent deformation. In the design of glass structures it is often necessary to laminate glass sheets to provide redundancy in the event of sudden failure of an element or leaf of glass, due to impact loading or spontaneous fracture by impurities inherent in glass.

The designer's choice of connection type is based on various criteria, notably strength requirements, adequate tolerance for construction, cost, method of fabrication and aesthetics. For both projects presented in this paper the transfer of load through the beam to fin is via a bearing type of connection. The transfer of load through a bearing connection makes use of the high strength capacity of glass and minimises the depth and complexity of the connection. This solution was first developed for the glass canopy of the Yurakucho subway station at the Tokyo International Forum by Dewhurst Macfarlane and Partners in 1996.

For the TIF Yurakucho canopy tests were carried out at City University, London, where the load and reactions for a three-point bending tests were applied to the glass sample through holes in bearing rather than edge loading. Results showed a mean strength of toughened glass as 160 N/mm<sup>2</sup>. From this a guide to allowable stresses for initial design of glass for short duration loads based on unfactored loads and using simple

elastic formulae, can be taken as the mean failure strength with an applied factor of safety of 3. The allowable stress for toughened glass would be 53 N/mm<sup>2</sup>. This compares well with the characteristic stress values given in the forthcoming Eurocodes (prEN 13474-1) currently in draft form.

The results of further tests on a 48mm diameter hole in a 19mm thick toughened glass sample with the load applied in pure tension gave a mean failure capacity of 77 kN. These results compared well with prediction by elastic analysis of stress concentrations around holes and together with the results of tests on laminated glass panels and square edged holes allowed the stress around holes to be accurately determined and a design method for the design of bearing connections in glass. One conclusion of the research was the importance of tight fitting bushes in true circular holes in glass in determining the load capacity, Wilson (1998).

### Glass conservatory, 'Teesdale', Surrey

The new building is a conservatory, joining the two existing wings of a large, single-storey house. The overall height of the existing building was quite small, and led to the option of having beams on the outside, which leaves the entire internal space free of obstructions. The option of external glass frames was immediately favoured by the client. Aesthetically, it contradicts the original building design, by Erno Goldfinger. Built around 1963, it consists of a series of glulam beams at about 2.5m centres, spanning across the whole width of the building. These beams are about 500mm deep and quite clearly divide internal space.



Figure 2  
*'Teesdale' – Grade II listed existing house in Surrey*

The overall aesthetics at 'Teesdale' were driven by the self-imposing rhythm of the glulam beams spanning across the whole width of the adjoining buildings. This idea of creating a clear span was taken further and to similar effect but using glass beams as opposed to timber ones. Due to the width of the original building and the client's requirement for maximizing the space, the length of the glass beams worked out at 6.9m, which is believed to be the

longest glass structural beam ever used in the UK. Due to its length and the aspect ratio, it has only been possible to make them in Germany because of the manufacturer's capability and experience.

The fact that the glass conservatory would be the subject to extensive solar gains in the summer, would make the space very hot and uncomfortable. Air conditioning was ruled out as it would require some sort of ductwork which would be unacceptable, having in mind tight headroom, and would interfere with the 'universal space' concept of an undivided room. Use of solar control coating solves this problem, by

reflecting some of the solar energy back to the outside and therefore the room is not overheated. Typical performance values of the double-glazed units used on this project are:

- U-value – 1.4 EN673
- LT – 65% (Total light transmission)
- Solar Gain – 36%
- Reflectance – 10%

The extra long glass beams, are comprised of three sheets of 12mm thick toughened laminated glass. In order to deal with 'roller wave' formed during the toughening process, a double PVB interlayer was used to minimize the risk of contact between two sheets of glass. The top edge of the

Figure 3  
*Three dimensional visualisation of the new glass conservatory at 'Teesdale'*

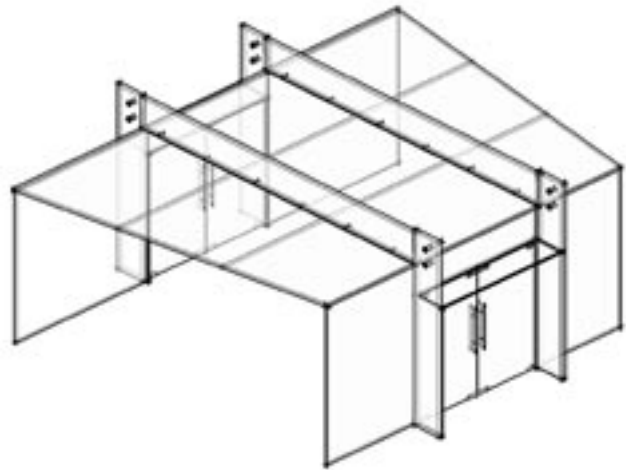


Figure 4  
*Elevation and section of a beam to fin connection in the glass conservatory*

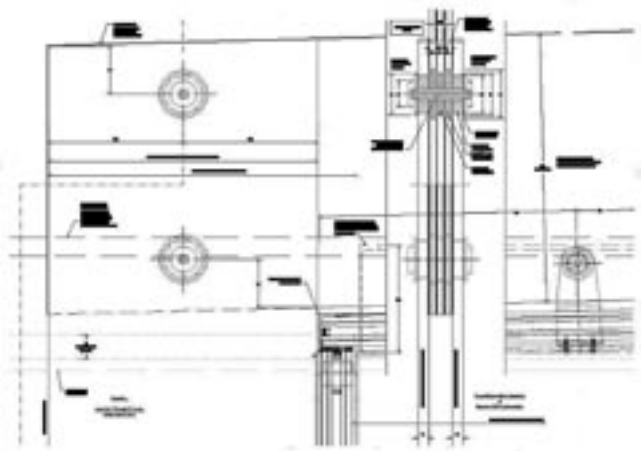


Figure 5  
*Section through the connection between glass beam and roof panels.*



glass beam is sealed with clear silicone, to protect the interlayer from water, which could cause delamination.

The aesthetics of the connection between the beam and the fin was again borrowed from the original design for the house, where two bolts placed vertically provide the load transfer. Due to the couple formed, some degree of moment fixity is provided to the beam ends.

However, due to the fact that the relative stiffness of the nylon bushes, used in the connection, is much smaller than that of the vertical fins, only about 10% of the full moment fixity is generated - making the beam effectively simply supported. Increased risk of buckling, though, is partially reduced by the fact that the loads to the glass beam are applied below the neutral axis and therefore some stabilising effect is taking place.

### Glass conservatory, Bartholomew Villas, London

Similar details have been adopted for another glass conservatory, at a house in North London. The all-glass enclosure rests on an existing first floor terrace, built to the rear of the town house which was designed by architect Edward Cullinan in the 1980s. External glass fins and beams provide the necessary structural frame to support a double-glazed roof and wall panels with overall plan dimensions of 3x3.5m.

Working with artist Gerry Judah and his architect partner Helen Bowers, glass fins and beams were chosen as external elements for the extension, to express the structural skeleton as sculpture. The glass beams are raked upwards at a steep angle from the rear wall, as if reaching up to the sky.

The provision of external glass fins bolted at the base to the face of a masonry wall, leaves the existing upstand unobstructed by vertical structure and can be used by the client for seating. The joint of the fins and beam is formed by two 60mm diameter stainless steel bushes. In all, the clear internal volume permits unrestricted views out to the south of the building.

Each fin consists of two 15mm-thick layers of single-toughened glass, 400mm deep. The glass beam comprises two 15mm-thick layers of laminated toughened glass, 400mm deep. These sleeve between the two glass fin sheets with a bolted fin-to-beam connection that follows the bearing detail designed for the 'Teesdale' project. In the same manner as at 'Teesdale', the roof panels are hung from the glass beams with fittings at 600mm centres and integrated with a thermal break.

The cantilever of the fins from the terrace is used to support a laminated glass floor and the sides of the protruded portion include window panels that provide ventilation to the internal volume.

Figure 6  
3-dimensional visualisation for the glass conservatory at Bartholomew Villas, London

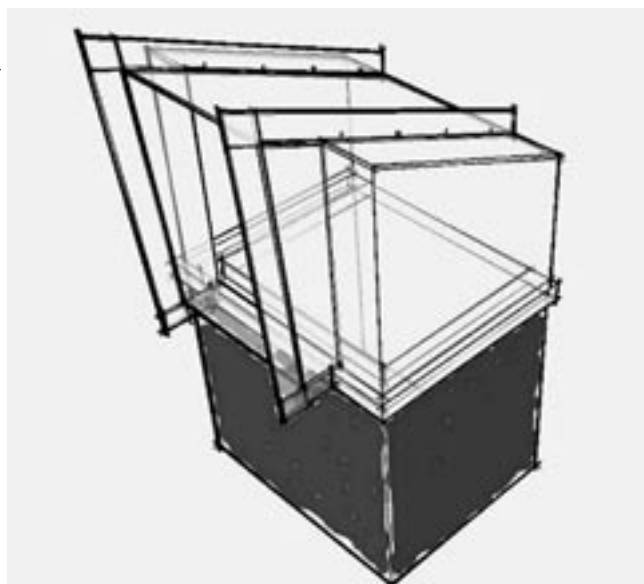
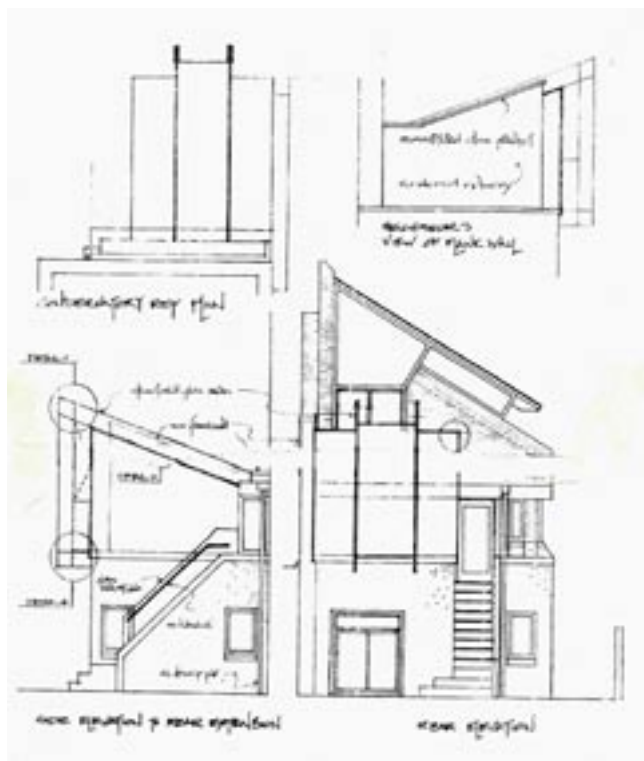


Figure 7  
Elevations and sections of the proposed conservatory at Bartholomew Villas, London



The flank double-glazed wall panel, adjoining the neighbouring property, is manufactured with a screen-printed sheet - offering a one-way vision that satisfies party wall conditions.

### Summary

The work carried out for the two projects described in the paper has shown that external glass frames are a feasible alternative to standard all-glass construction with suitable attention to detail in both design, fabrication and construction and by the provision of redundancy by using laminated glass.

For both projects all wall and roof units were treated with a high performance 'soft' coated double-glazed units to reduce solar gain and which looks set to become standard for all-glass structures with high levels of sun exposure

The selection of the connection method depends largely on strength requirements, adequate tolerance for construction, cost, method of fabrication and aesthetics. The transfer of load through a bearing connection requires a high level of precision in fabrication.

### References

- [1] prEN 13474, Glass in Building - Design of Glass Panes, Under Development
- [2] Wilson, P (1999) Bearing technology in glass, Glass in Buildings, Bath
- [3] Wilson, P (2005) Construction Practice in Glass Structures, Final Report, WG3 Structural Aspects of Glass, COST C13