ENGLISH HERITAGE
PRACTICAL BUILDING CONSERVATION

GLASS & GLAZING

ENGLISH HERITAGE

ASHGATE

Architectural glazing may be roughly divided into two types: windows, and glass used as a material for roofing and walling (which we refer to as 'modern glazing'). Each has its own conservation needs, and the second and third sections of the book look at these in detail.

In this first section, the aspects of conservation common to both types of glazing are discussed. The first chapter includes a history of architectural glass manufacture, showing how this has led to changes in glazing technology. It is followed by chapters on the way glazing deteriorates, how this deterioration should be assessed, and how it should be conserved and maintained.

Light is a precious commodity in buildings. The English word 'window' is derived from the Old Norse '*vindauga*', meaning 'windy eye': the openings in walls that were so necessary to let in light also let in the weather. This meant they had to be sealed in some way, and in the past many translucent materials were used for this purpose, from oiled parchment and waxed paper to split horn and mica, or thin sheets of alabaster. As late as the end of the 19th century agricultural workers in the East Riding of Yorkshire were still using a coarse sack cloth for the windows of their cottages, and in County Donegal in the west of Ireland, strips of sheepskin were being used in the same way.

Glass proved indisputably the best material for windows. Transparent but waterproof, it could also be shaped and facetted and coloured, so it became as decorative as it was practical. Treated with care, glass window panes could be very long-lived, and broken panes could always be remelted and used to make new glass. This was necessary: glass is so ubiquitous in our own times that it is difficult to remember that until cheap fossil fuels and improved technology arrived in the Industrial Revolution, it was extremely expensive to make, and could only be produced in very small pieces. Until well into the 17th century, glass windows were mounted in such a way that they could easily be taken from house to house, and in inventories they were valued separately from the building itself.

Glass has such obvious benefits as a building material that, even when it was still extremely expensive, it was used whenever and wherever possible, and it proved central to modern architecture, as much for its water-resistance as for its transparency. Indeed, developments in glass-making technology have been one of the most important factors shaping architectural development, as a brief history of architectural glass and glazing shows.

HISTORY OF GLASS & GLAZING

Glass fulfils such an important role in architecture that it is difficult to find buildings which do not rely at least to some extent on its combination of transparency and weatherproofing. Solid-walled buildings use glass windows to let in light and air whilst keeping out rain and wind, and much modern architecture relies on walls and even roofs of glass.

Recording Techniques

THE PURPOSE OF RECORDING

Recording is an essential part of conservation and visual recording serves several purposes. A written record may make more sense when supported by illustrations of features or phenomena that are hard to describe in words, or where terms used might mean different things to different people. Visual recording is also a means of defining the appearance of a structure at a particular time, and of mapping its condition or treatment. Condition mapping repeated at intervals over time can be used to assess rates and patterns of deterioration.

SELECTING A RECORDING TECHNIQUE

Techniques for visual recording range from simple sketches, through photographs and measured drawings, to sophisticated methods such as laser scanning and photogrammetry. Developing technology means there will always be new methods available, offering increased capability or greater accuracy, but the choice of technique must always be appropriate to the individual project. Which techniques are feasible will depend on the circumstances and available resources; which are appropriate will depend on the type of information required, the significance of the object or building, and the scale and goals of the project.

Selecting a visual recording technique should take into account:

- the purposes of the visual record
- the nature and significance of the structure or feature
- how much is already known, and the availability of any existing data
- the required level of detail and accuracy
- the costs and benefits of the proposed techniques.

Even where cost is no object, some techniques will not be feasible for reasons of access, and others because they pose an unacceptable risk to the fabric. Where possible, preference should be given to techniques that are independent of interpretation (for example, photography as opposed to drawing).

RECORDING TECHNIQUES

DRAWINGS

Sketches and measured drawings can be the easiest and simplest way of recording structures and details, and of creating a base map for condition mapping. Dimensions can be measured by hand, but speed and accuracy are improved by using reflectorless electronic distance measurers [REDM].

Drawing has the advantage over photography of being able to include concealed elements such as structural frameworks. Whilst drawing is dependent on the artist's interpretation, the advantage is that it forces close inspection.

A photograph of a detail should always be accompanied by large-scale photographs which places it in context.

PHOTOGRAPHY

Photographs are an excellent means of recording appearance and condition at a particular time, and can also be used as a base map for simple condition mapping. They are a critical tool for assessing significance and condition, and are also particularly useful for illustrating reports. Limitations include the need for reasonable levels of lighting, and the difficulty of recording parts of the structure that are concealed behind projections. Glass is difficult to photograph well, and it may be necessary to try a range of different camera angles and types of lighting to record it effectively.

Photographs are most useful when the subject can be accurately located and identified, so general photographs should be taken of the structure and its surroundings, to allow the location of close-ups to be pinpointed. It is useful to frame detailed photographs in such a way that their location will be clear to others in future.

For macro images, some means of indicating size should be included (a scale bar, for example). Variations in surface topography can be highlighted by lighting from an oblique angle (raking light). If necessary, a standard calibration bar can be included in the photograph, to indicate the true colours. This can then be used to correct the colours of digital images if required.

Construction of Glazed Panels

LEADED LIGHTS

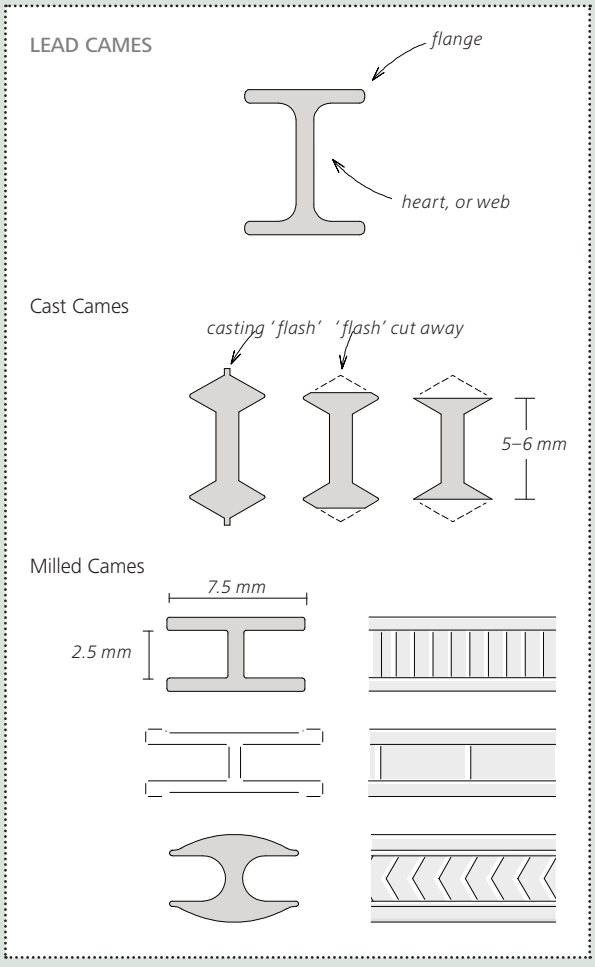
The earliest glazed panels were leaded lights, made up of small pieces of glass held together in a framework of lead, and supported where necessary with frames or bars of wrought iron. The basic design stayed virtually unchanged for centuries: almost all Tudor and Jacobean windows were made in exactly the same manner, and stained glass windows are made this way still.

Lead is malleable enough to be bent around elaborately shaped pieces of glass. Although leaded panes of shaped and coloured glass were most commonly found in churches, they were sometimes used for important secular buildings as well, and even for some houses. In the 19th century and early 20th century, domestic stained glass became very popular (see the **Special Topic: Ornamental Architectural Glass**).

The glass had to be cut into small pieces (or 'quarries') that fitted neatly together. For stained glass, the quarries needed to be shaped in complicated ways to follow the design, with careful allowance being made for the space taken up by the heart of the came, but for plain glass panels manufacture was much easier: all the quarries were cut to the same size and shape, most commonly into diamonds. These 'lozenges' made the most efficient use of the sheet of glass, since off-cuts could be used to fill the small triangles left at the edges and corners of the panel. The lozenge shape also proved functional: when larger pieces of glass became available in the later 17th century, and there ensued a fashion for square or rectangular quarries, the panels were found to be much more likely to buckle as the soft lead crept.

Even when no longer at the height of the fashion, lozenge-shaped quarries continued to be popular for humbler buildings, and for architecture aspiring to a 'cottage' style.

Cames were made of lead formed into a strip which in cross-section resembled a letter H, with slots that were slightly wider than the thickness of the glass. Throughout the medieval period, cames were cast into shape, but later it became common to mill them or extrude them after casting, producing longer lengths and custom widths. Milling had the unfortunate side-effect of making them rather less durable.



To make up a window from lozenge-shaped quarries, the craftsman had to work on a flat table, marked with the pattern that was to be followed. Starting at one corner, a length of came was cut to run diagonally across the window, and quarries were inserted into this. Between neighbouring quarries smaller sections of came were inserted, each cut to the length of one side of a quarry, and in this way the panel was built up. The lead pieces were then fused together at their joints with molten lead (solder was introduced for this purpose in the mid-19th century), and finally the cames were secured and the panel made weatherproof by forcing into the space between the glass and the cames a soft putty, or a 'glazing cement', based on powdered chalk, linseed oil and turpentine.

Chronology of lead cames

Early cames were cast into shape from molten lead, and the flanges trimmed to size.

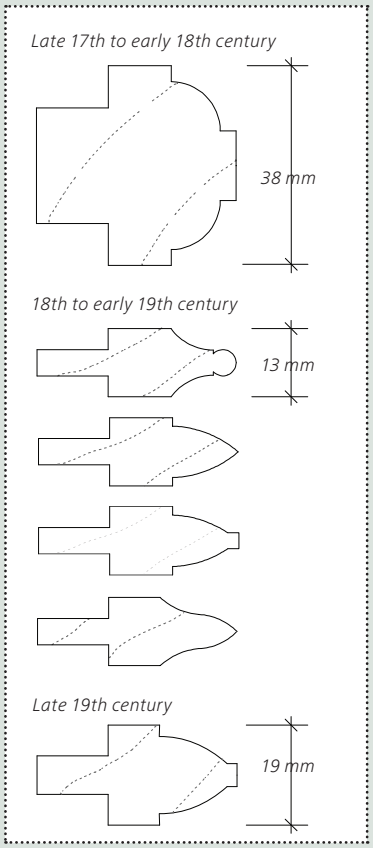
Production by milling may have been introduced as early as the 15th century in Germany, but the heavier cast cames were considered superior, and remained the preferred choice for several centuries, especially for stained glass.

WINDOW PANELS CONSTRUCTED WITH GLAZING BARS

As larger sheets of glass became available, it became possible to form glazed panels with timber 'glazing bars' to hold the individual pieces together, rather than lead cames (which could not have supported the weight of glass). The size of the individual panes and the number of glazing bars in a sash were directly related to the importance of the building. Large rectangular glass panes were not only more expensive, but at greater risk of being broken; and a broken large pane was much more expensive and difficult to replace than a broken quarry or small pane.

To form a panel with timber glazing bars, the framework on the exterior side is rebated, and the rebate laid with a bed of putty, into which the glass pane is pushed before being pinned in place using glazing 'sprigs' (small, sharp brads). More putty is applied over the joint to waterproof it, profiled to shed rainwater, and finally the putty and frame are given a protective coating of paint: originally this would have been an oil paint, and almost certainly would have included white lead to help it dry. Although most panels were made with straight wooden bars, complex shapes are perfectly possible and by no means uncommon.

The size and profile of the glazing bars can be a good guide to the age of a window, since they varied greatly over time, as glass technology developed. Until the 20th century, the fashion was to make the panes of glass look as large as possible, which in simple terms meant that the glazing bars became thinner over time.



Glazing bars can be a guide to the age of the window

The thickness of the bars, and the elaborateness of their profiles, were characteristic not just of the importance of the building itself, but of the relative importance of the window within the building: plain bars were used for service-room windows or servants' quarters, and moulded bars were used in reception rooms. It is not uncommon to find 18th-century and early 19th-century houses where there are two or three different styles of window with different glazing bars, all dating to exactly the same period.

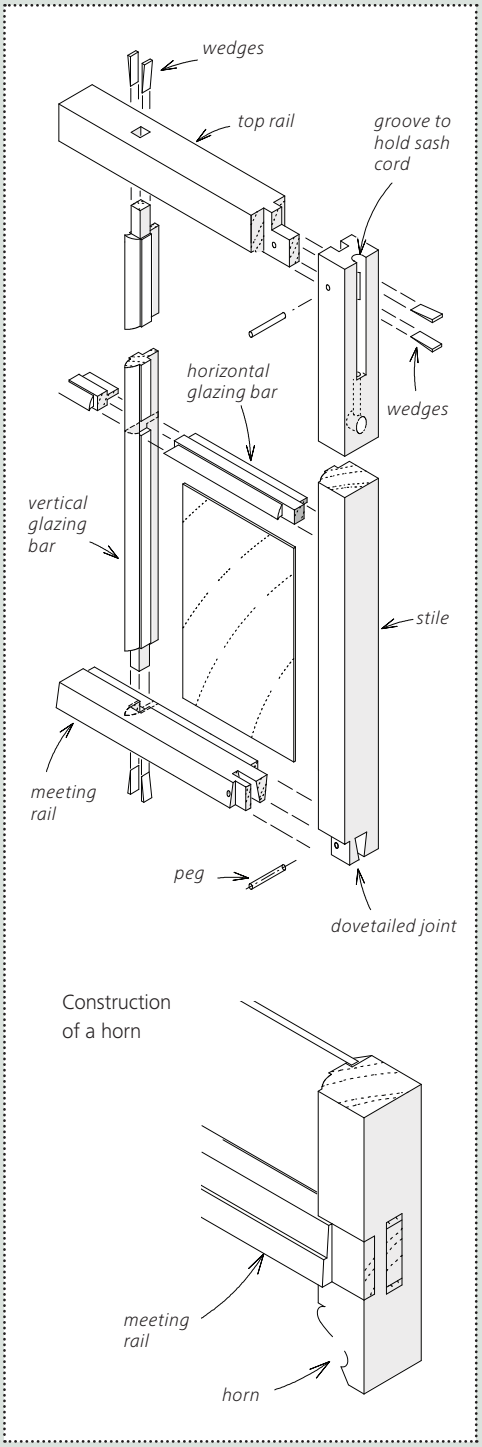
Left: The thick glazing bars of early sash windows were replaced by fine bars profiled to appear even thinner. Late 19th-century bars became thicker again, to support larger (and heavier) pieces of glass.

Right: Glazing bars could sometimes be very elaborate.

Construction of timber panels for opening windows

Top: Typical construction of an 18th-century top sash for a vertically sliding sash window. The vertical glazing bars help to support the meeting rail.

Bottom: When panes became larger and thicker – and heavier – in the 19th century, and window panels were produced with fewer glazing bars, it became necessary to reinforce the frame with 'horns': extensions of the stiles that stopped the bottom rail dropping out.



A 1732 glazier's advertisement (in the ***London Evening Post*** of 27th June) shows that early Georgian windows had glazing bars almost 4 cm thick: *"Thomas Lovett... at the Green Lamp in Red-Lion St Holborn... sells the best Crown Glass for forty shillings the half case, likewise the same proportions by the single table, and those that have a mind to have it cut to any dimensions for 7d per foot; and for the second sort of Crown Glass for 6d per foot; also wainscat sashes 1 inch and a half thick, ready glazed, for 1s per foot, to any dimensions."* By the early 1800s, the average thickness was around 12 mm. Oak had been the wood of choice, but Baltic softwood became popular early in the 18th century (mahogany was also used in the 18th century, but only very occasionally, and then only in the most luxurious houses). Baltic pine is close-grained, which meant that the glazing bars made thinner (for reasons of longevity, oak continued to be used for the cills).

Over the course of the 18th century glazing bars became so thin that, for larger windows, timber was sometimes replaced by metal. Metal glazing bars were mostly cast-iron, but copper and bronze were also used, and more occasionally other metals. These were usually cast as T-sections, open towards the outside of the window and detailed to imitate the timber bars (with glazing rebates and decorative internal mouldings), but entire windows were sometimes cast as well. This allowed more elaborate patterns to be made quite cheaply. The glass was held in place with spring clips, before being sealed with putty as with a timber frame.

When (in the middle of the 19th century) glass was no longer taxed by weight, and cylinder glass became affordable, the larger sheet sizes were exploited by reducing the number of bars (often to a single bar, dividing the sash in two). The bars themselves became a little thicker again, to cope with the heavier weight of glass, and sashes were reinforced with timber 'horns' to stop the bottom rail falling out.

SPECIAL TYPES OF WINDOW

PROJECTING WINDOWS

Bow, bay and oriel windows let a great deal of light into rooms, and so have been popular since glass first became available for windows, especially for ladies' workrooms. They were also the window of choice wherever a wider view was desirable, and thus are a feature of inns and stagecoach stops (where the occupants needed to be able to see up and down the street). As Chris Partridge wrote in ***The Observer*** in 2005, describing the oriel window of a house in Hampstead: *"From this window, generations have watched Samuel Johnson and David Garrick visiting the spa next door for their health, John Constable taking his sick wife to No.40, John Keats looking peaky and D. H. Lawrence being not at all well at No.32."*

Victorian architects took the projecting window even more to heart, and it is the characteristic feature of the great majority of Victorian and Edwardian terraces and semi-detached houses. 'Baronial-hall' office buildings such as those in Manchester had bays and oriels glazed with curved glass, for which purpose cylinder glass proved ideal.

Projecting windows were ideal for display, and as glass became slightly cheaper they were quickly adopted for shops.

TYPES OF PROJECTING WINDOW

BAY WINDOW	ORIEL WINDOW	BOW WINDOW
		
Bay windows have foundations on the ground, and may be one or several storeys high. On late Georgian buildings it is not uncommon for bay windows to extend right through three floors to the roof, particularly in seaside resorts where the view was very important.	Oriel windows are confined to the upper storeys, so that they jet out from the wall. They were common features of medieval buildings, but their charm and utility has meant they never entirely disappeared from fashion at any period.	Bow windows are curved rather than polygonal in plan, but can be either bays or oriels. Georgian bow windows were often glazed with small flat panes: this was a considerable test of woodworking skills.

SHOP WINDOWS

Transparent window protection not only lets occupants see out of the building, but lets passers-by see in. Glazed shop-fronts make it possible to display goods whilst still keeping them protected from the weather and from theft, and shopkeepers were amongst the first to exploit the advances in technology that made sheets of glass ever larger. By the end of the 18th century, even though glass was still extremely expensive, most shops had changed from open displays (with shutters that had to be closed up at night) to windows, often bowed to increase display space.

The earliest shop windows were composed of small panes, with an overall width constrained by the span of the load-bearing lintels (or 'bressumers') above the window opening. The result was startling and set off a craze, described by Charles Dickens in ***Sketches by Boz*** in 1836: *"The primary symptoms were an inordinate love of plate glass, and a passion for gas-lights and gilding. The disease gradually progressed, and at last attained a fearful height. Quiet, dusty old shops in different parts of town were pulled down; spacious premises with stuccoed fronts and gold letters, were erected instead; floors were covered with Turkey carpets; roofs supported by massive pillars; doors knocked into windows; a dozen squares of glass into one..."*

Always in search of new ways to advertise their wares, shopkeepers exploited the technological advances in glazing as soon as they could.

Right: Although glass was still very expensive, bressumers were inserted in façades to allow for new windows with the largest possible expanses of glass, as can be seen here in the 12th-century Jews House on Steep Hill in Lincoln, one of the oldest town houses in England.

Display is the primary purpose of shop windows

As larger sheets of glass became available, multi-paned windows quickly disappeared from shops. By the 1830s, long before the glass tax was repealed, a furrier on Regent Street in London had installed a window of hand-polished plate glass that measured 3 m x 1.5 m, and cost the enormous sum of 50 guineas.

The earliest shop windows also served to illuminate the premises, but as artificial lighting became cleaner and more reliable, this function became less and less important. Many modern shopping centres have almost entirely dispensed with natural lighting, reserving the exterior walls for storage and shelf display, and using glass as frontages for an array of smaller shops inside the main building.

As architectural elements began to be made of metal, the size of windows was increased by using slim structural columns of cast iron, in combination with ever larger sheets of plate glass. The distracting glazing bars could be minimised and eventually eliminated, and designers exploited the natural curve of cylinder glass to make rounded windows that were perfectly suited to enticing displays. ➲METALS

As float glass became available, complete frontages were clad in glass at street level to make continuous runs of window. By this time, the sole purpose was display: electric lighting had made natural lighting through glass windows and roofs redundant, and windows were boarded over internally so that wall space could be devoted to display shelves and storage. The most recent innovation is the shopping centre, where the external walls may be almost entirely devoid of windows, but glass is used for internal walls that also act as shop frontages (**Modern Glazing** has more information about the use of glass for shop frontages and roofs).

It was about the same time that the most noted manufacturer of ready-made fanlights, Francis Underwood, set up shop in London. For the next 60 years his company was by far the major supplier, though he quickly faced competition from rivals such as James Kier, whose lights were decorated with his and Matthew Boulton's own patent 'Eldorado metal', a gold-coloured alloy.

By the late 1780s fanlights were beginning to incorporate coloured glass as well. In 1789, Kier's company introduced a 'universal' fanlight, produced in a standard size, but able to easily be cut down or extended to fit almost any space.

Fanlights

Semi-circular transoms are more commonly known as 'fanlights'. These began to appear in the first quarter of the 18th century, and may have grown out of the fashion for round-headed windows. They were certainly a good way of using oddly shaped scraps of glass, and many fanlights had ornate glazing. They were only rarely made openable.

Decorative Painting of Window Frames

Paints have always been the most common finish for window frames made from water-sensitive materials such as softwood and ferrous metals (wrought iron, cast iron or mild steel), and the paint was often used for decoration as well as for protection. Even oak frames, which could be left untreated, were commonly limewashed, or stained with materials such as pigmented oil or ox blood. In rare instances they were gilded (as they were at Chatsworth, in Derbyshire). When thin glazing bars were the height of fashion, the putty was sometimes painted in dark colours to make the bars appear still thinner. It is difficult to establish a clear chronology of fashionable colours: many windows were replaced when plate glass was introduced, so much early paint has been entirely lost.

The paints most commonly used for ironwork were mostly very similar to those used for protecting softwood, being based on white-lead pigment in linseed oil. The lead helped the paint to dry, and the result was very robust. It was not bright white, but a creamy off-white (often described as 'stone colour'); sometimes other pigments were included to make a coloured paint.

PAINTS USED ON METAL

As well as lead-based oil paints, lacquers, varnishes and waxes have all been found on wrought ironwork, and bitumen paints were also sometimes used. Bronze windows were typically coated with clear or tinted lacquers, or with natural waxes and oils, usually after having artificially patinated to appear brown (naturally green bronze window frames are quite uncommon).

In the 20th century, steel windows began to be finished with elaborate paints and lacquers; some contained metal powders to imitate bronze or aluminium. By the 1950s, steel frames were being powder-coated or stove-enamelled. Galvanising was made mandatory in 1955, but early examples are now rare, and so should be preserved if possible. The aluminium frames which soon replaced galvanised steel were often anodised. ⊃METALS

PAINTS USED ON TIMBER

Most early softwood sashes appear to have been 'stone colour'. Surviving coloured designs from the end of the 18th century do suggest that sometimes darker colours were used, but they are not commonly encountered during paint analysis.

During the 19th century the range of finishes became wider. From the 1820s there was a fashion for 'graining' (painting to imitate oak and other woods), which was carried out in tinted lead-based oil paints and finished with protective varnishes. A specification from the 1840s, for painting a small terraced house in London, asks for the sashes to be finished in 'dark purple brown', and decoration seems to have become less and less prescriptive. Sample specifications from the later part of the century suggest that most windows were finished 'to choice', and so could be light, dark or grained. Stone colours of various shades remained popular, but were joined by purple-brown, chocolate, brown 'oak colour', drab, and various types of green. Early photographs show a range of different shades.

In the 1960s, traditional lead paints began to be replaced by modern paints, which allowed the very bright whites that are now the commonest choice for painting windows. Black is an alternative seen from time-to-time, and this too has been made possible by modern paints that are able to set very quickly, since black pigments tend to slow drying. ⊃TIMBER

TYPES OF GLASS

CAST GLASS

An opaque glass, usually very thick, made by casting (as the name suggests). The upper surface is rolled, producing parallel ridges.

Cast glass was used to produce hand-polished plate.

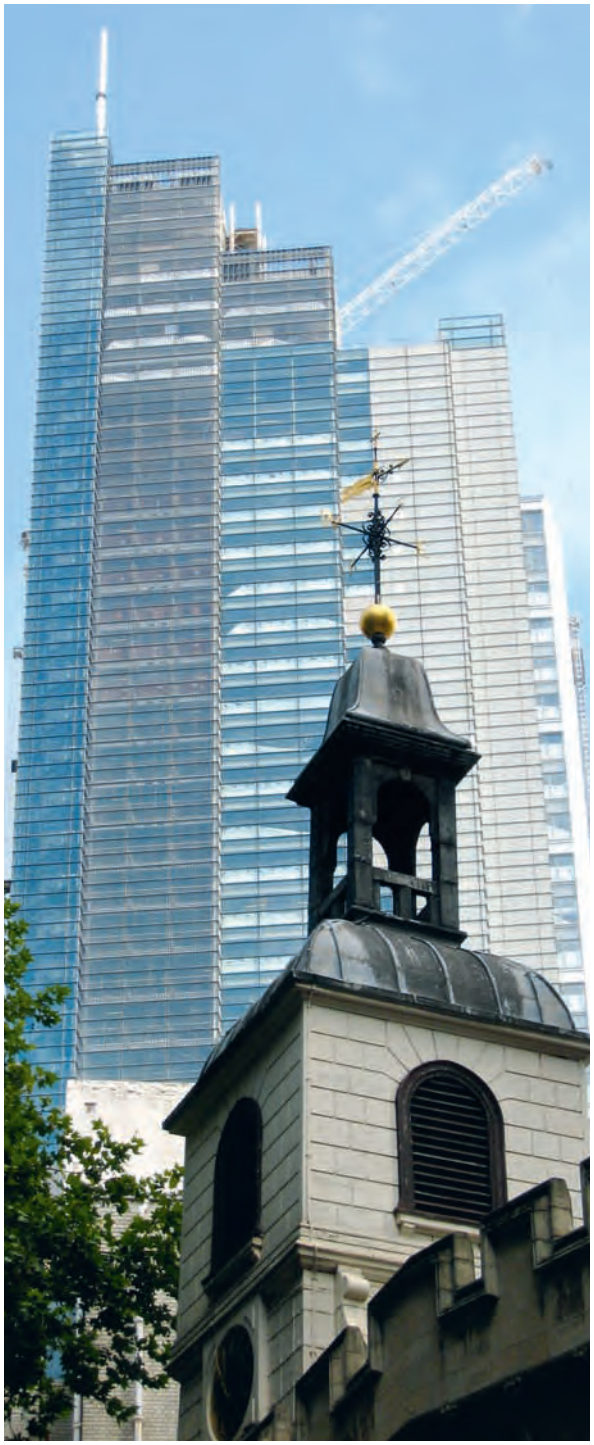
CATHEDRAL GLASS

Glass that is made opaque by impressing a pattern into the surface.

TYPES OF GLASS

NORMAN SLAB

Dark-coloured glass produced by blowing a glass bubble into a rectangular box form; the resulting vessel is then cut along the corners to create five rectangular pieces of glass, each of which has thin edges and a very thick centre.



By the 1970s, most curtain-walling mullions were being made of aluminium, extruded to give pockets into which the glass panels slotted neatly. This was not without problems: although the metal was much lighter and more corrosion-resistant than steel, it also bent much more under load (deflecting as much as three times more than an equivalent section in steel). This could fracture the glass, or cause it to pop out of the mullion, so the shape and depth of the mullion had to be adjusted, and sometimes they needed to be reinforced with steel.

Another change was the introduction of 'thermal breaks' of some insulating material (usually polyvinyl chloride [PVC]) at the meeting points of interior and exterior metal members, to prevent condensation and subsequent corrosion. This had the disadvantage of somewhat reducing the stability of the structural system. Often, rigid insulation was also added to the 'spandrels' (the horizontal sections of glass differentiating between adjacent floors).

Construction of Curtain Walling

In traditional building construction, the walls of the building carry the weight of the roof and of the floors and walls above, and this necessarily limits the height of the building. The introduction of reinforced concrete, and cheap and reliable iron and steel, allowed buildings to be constructed in a new way: with a load-bearing framework of columns and beams, from which could be hung a waterproof cladding of panels that did not themselves carry any load other than their own weight, and the live loads of wind and impact.

STRUCTURE

Early curtain walls used 'stick systems' based on vertical and horizontal framing members (the 'sticks'), and most installation and glazing was completed on site. In the 'unitised systems' introduced in the 1990s, the frame and panels are made into 'units' off site, and then simply hung in place on the building. Both stick and unitised systems are still in use, and there are also hybrids such as 'stick and cassette' systems.

PRIMARY STRUCTURE

The building's structural frame, from which the curtain wall is hung, is a skeleton that must be robust enough to support the loads imposed by the curtain wall itself (which will change continually, particularly with alterations in wind pressure).

The primary structure can be made of any structural material, including wood, but steel and reinforced concrete are the most common choices. The brackets that attach the curtain-wall framework to the floor slabs have most commonly been made of aluminium, either fabricated or extruded, or from fabricated mild steel. In rare cases, stainless steel has been used.

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