8

STRUCTURE AND LIGHT

INTRODUCTION

Following the view that architectural space exists when it is experienced by the senses, particularly sight, Van Meiss considers architectural design to be 'the art of placing and controlling light sources in space'.[1] He understands light sources to include actual light sources such as windows as well as illuminated objects like enclosing surfaces or other architectural elements that could include structural members. From this perspective, structure is potentially an important architectural element – both as a source of light, where light passes through it or illuminates it, and also as controller of how and where light enters a space.

When stone and masonry load-bearing wall construction dominated previous periods of architectural history, openings for light could be considered the absence of structure. Millet's description of the relationship between structure and light is particularly applicable to that former era. Focusing more on structure's potential to control light than function as a source of light itself, she writes: 'Structure defines the place where light enters. The structural module provides the rhythm of light, no light. Where the structure is, there is no light. Between the structural elements there is light.'[2] However, since the introduction of metal skeletal structural forms during the nineteenth century, it is no longer a case of either structure or light in architectural space – both can co-exist. Slender structural members have a minimal impact upon the amount of light entering a space. Whereas the former prevalence of masonry structure, in plan and elevation necessitated its penetration in order to introduce light, in current architectural practice daylight requirements frequently determine structural form and detailing. Contemporary structure with its relative slenderness and small plan 'footprint' can usually meet these demands.

Depending upon its configuration, structure either inhibits or facilitates the ingress of light. In a building with perimeter structure that does not exclude natural light, structure relates to light in one of four modes – as a source of light where, for example, light passes through a roof truss to enter a space; to maximize light by minimizing the shadow effect of structure; to modify light by reflecting and diffusing it; and occasionally, for light to affect our perception of structure.

The following sections of this chapter discuss each of these modes, but before moving on to them, Louis Kahn's contribution to the integration of structure and light must be acknowledged. Consider one of Kahn's developments – light-filled columns:

> *As early as 1954, he had the idea that the column could be hollowed out so that its periphery became the filter for light entering the column … In 1961 Kahn began the Mikveh Israel Synagogue Project in Philadelphia. Here he inserted hollow columns into the exterior walls at intervals. These nonstructural cylinders act as diffusion chambers. Daylight shines through their exterior openings, ricochets around the inside of the columns, and filters subtly through openings into the synagogue … Kahn was beginning to use the hollow column as a sophisticated light-regulating device.*[3]

Kahn went on to use structural columns as light-regulating members in the National Assembly building at Dacca, but the Kimbell Art Museum is perhaps the best-known building to illustrate his aphorism 'Structure is the giver of light'.[4,5] Daylight penetrates through longitudinal slits in the vault-like shell roofs only to be reflected up against their concave surfaces. Light that is uniform in intensity and diffuse in quality illuminates the art works. Structure also functions as both source and modifier of light in some of his other buildings. His Philip Exeter Library is a notable example. Roof light entering the full-height central atrium reflects off two-storey-deep concrete beams that span from diagonally opposite corners.

The giant X beams are visually scaled to the height of the space. They also act as baffles and registers for the clerestory light. 'In the central space of Exeter, a sober, grave, and noble character is realised, not only by the interaction of the indirect *lumière mysterieuse*, filtering down the grey walls from above, and by the sombreness and ashlar-like articulation of the concrete screen walls.'[6]

Source of light

This section explores examples where structure functions as a primary source of direct light, rather than as a source of modified or reflected light as exemplified by Kahn's works. While the sun is clearly the source of all natural light, the term 'source of light' is to be understood as describing the method of admitting natural light into a building. After noting how some structural forms facilitate entry of daylight into a building, it is observed how open structural forms like trusses, and even areas where structural members are normally connected, admit light. Several examples then illustrate a common situation where structural

▲ **8.1** Stellingen Ice Skating Rink and Velodrome, Hamburg, Germany, Silcher, Werner + Partners, 1996. Daylight enters the junction between the flying-strut and the fabric membrane.

member layout defines the ingress of natural light. Finally, attention turns to artificial light sources that are fully integrated with structure, in contrast to the usual practice of simply mounting or hanging them from structural members.

Some structural forms are far more suited than others to allow daylight to penetrate into building interiors. For example, the skeletal quality of structural moment-resisting frames is more conducive to the passage of light than opaque structural walls. However, other less common structural forms also provide opportunities to admit light. These areas tend to occur where different structural systems within the one building meet, as in the case of the catenary and masted systems at Hall 26, Hanover, and the Wilkhahn Factory, Bad Münder (see Figs 3.11 and 4.27). In both of these buildings light penetrates the roof where the catenaries connect to the masts. In another example at the Stellingen Ice Rink, Hamburg, the junctions between points of compression support and the fabric roof serve as direct light sources. Even though the fabric roof is translucent enough to transmit a small percentage of the external light, openings in the fabric beneath the mast-tips and above the flying-struts explicitly invite daylight into the space (Fig. 8.1 and see Figs 3.7 and 3.8).

The most common situation where structure functions as a primary light source occurs where light passes through an open or skeletal structure like a truss while being excluded from surrounding areas by opaque cladding. Architects prefer the width, and occasionally the depth of open structural members as primary daylight sources. Structure rarely acts as a longitudinal conduit for daylight and well-known precedents are limited to Kahn's hollow columns and some of the tubular lattice-columns at Toyo Ito's Sendai Mediatheque.[7]

Daylight is introduced into the central area of San Francisco International Airport, through specially shaped trusses. While very narrow strip skylights are positioned immediately above the top chords of the two-dimensional trusses located near generously glazed side-walls, the middle trusses widen in order to become sources of light (Figs 8.2 and 8.3). Although still maintaining the elevational profile of their neighbours, these trusses have the same lenticular geometry introduced into their plans. Their entire upper surfaces are fully glazed but direct sunlight is excluded by tautly stretched translucent fabric. On a sunny day, the space under these trusses is more brightly illuminated by daylight than the side areas that gain light directly through the adjacent walls. Whereas the diagonal members in the side planar trusses consist of both steel tubes and tension rods, the central three-dimensional trusses use fine rods only to maximize the intensity of the diffuse light.

▲ **8.2** San Francisco International Airport, USA, Skidmore Owings & Merrill LLP, 2000. A two-dimensional truss transforms into three dimensions over the central span of the terminal.

▲ **8.3** Light passing through a three-dimensional truss.

▲ **8.4** Dome Leisure Centre, Doncaster, England, FaulknerBrowns Architects, 1989. A glazed truss-to-column connection.

At the Dome Leisure Centre, Doncaster, triangular roof trusses project above the roof plane that attaches to the truss bottom-chords (Fig. 8.4). Where the trusses are glazed, their sloping sides function as strip skylights. The Carpentry Training School, Murau, displays a similar approach (see Fig. 7.23). Here the roof plane meets the primary truss half-way between the top and bottom-chords. The top half of the sloping sides of the truss are glazed and light also enters from perimeter clerestory glazing.

A stepped roof form at the Kew Swimming and Recreation Centre, Melbourne, provides another alternative to conventional surface-mounted light sources such as roof skylights. The step in the roof becomes a near-vertical glazed surface and creates a more interesting exterior form and interior space compared to a horizontal roof and skylight (Fig. 8.5). In this building the truss depth rather than its width determines daylighting levels. Natural light passes through the truss that spans the length of the building, into the main pool area. Given its overall lightness, the fineness of its members and their tubular form and neatly welded joints, the truss itself is an attractive architectural element.

Structure also acts as a light source, albeit infrequently, where light passes through an area of structure normally regarded, at least by structural engineers, as a critical joint region. The Baumschulenweg Crematorium,

▲ **8.5** Kew Swimming and Recreation Centre, Melbourne, Australia, Daryl Jackson Architects, 1990. Light penetrates the truss that defines the step in the roof.

▲ **8.6** Sant Jordi Sports Hall, Barcelona, Spain, Arata Izosaki & Associates, 1990. Light enters through constructional fold-line joints, as in this corner of the roof structure.

Berlin, where light audaciously enters the condolence hall through annuli at the column to roof-plate junctions and the longitudinal wall to roof connections, has already been visited. Both structural junctions, usually important from the perspective of gravity and lateral loads have had their load transfer mechanisms modified for the sake of light (see Figs 2.14 and 2.15).

Other cases of light passing through structural joints are exemplified in two sporting facilities. At the Stellingen Ice Skating Rink, Hamburg, mentioned previously, areas in the vicinity of the fabric and its supports are well suited for introducing light. The need for the fabric–steel interfaces to be dispersed in order to avoid puncturing or tearing the highly stressed fabric, rather than be concentrated, provides such an opportunity (see Fig. 8.1).

In the second example, light passes through joints into the Sant Jordi Sports Hall roof, Barcelona (Fig. 8.6). The unique feature of these joints is that they express the hinge or fold-lines necessitated by the Pantadome System of roof erection. In this construction method the roof structure is first assembled on the ground and then raised by hydraulic jacks. As the roof rises, hinges allow the central dome and peripheral areas to fold relative to each other, and when the roof is in its final position, additional structural members lock the hinge zones to stabilize the structure before de-propping.[8] Although many small skylights over the central dome also contribute to the lighting levels, the temporary hinged-joint regions are the primary light sources.

While designers arrange for light to pass through open structural systems or connections between structural members, most light enters a

▲ **8.7** Burrell Gallery, Glasgow, Scotland, Barry Gasson Architects, 1983. Repetitive yet attractive glass and timber restaurant enclosure.

▲ **8.8** Portuguese Pavilion, Lisbon, Portugal, Alvaro Siza, 1998. Light passes through the slit in the concrete slab and between the stainless-steel tendons.

building through penetrations in the external walls and roof cladding. These are usually positioned and shaped to respect the layout and geometry of the underlying supporting structure. Windows and skylights are normally positioned between structural members. The Burrell Gallery restaurant, Glasgow – a timber and glass 'lean-to' that wraps around the south-east corner of the gallery – provides a simple yet attractive example (Fig. 8.7). Natural light entering the fully glazed enclosure passes between closely spaced 330 mm by 100 mm glue-laminated timber posts and rafters. While a strong yet simple rhythm of structure and light characterizes the space, structure not only limits the daylight, but to some extent modifies it. Given that the posts and rafters are spaced at little more than twice their depths, the members create shade and also reflect light off their vertical surfaces.

Light passes between the structural members of the reinforced concrete catenary of the Portuguese Pavilion, Lisbon, far more dramatically (see Fig. 3.9). An unprecedented design decision led to the removal of a narrow strip of concrete at the northern end of the catenary that would normally cover the tension rods. Above the podium where visiting dignitaries to Expo '98 were publicly welcomed, sunlight filters through exposed stainless-steel rods. Striated shadows pattern the buttress walls that withstand the catenary tensions (Fig. 8.8). The project structural engineer, Cecil Balmond, describes the effect poetically:

> *Made out of concrete, the curve flies seventy metres without apparent effort – from afar it looks as if it is made of paper. And at the last moment of span, just before the safety of the vertical anchors, the form is cut. Lines of cables cross the void instead, pinning themselves to strong abutments.*

▲ **8.9** Railway Station at Satolas Airport, Lyons, France, Santiago Calatrava, 1994. Glazing centred over the main concourse.

▲ **8.10** A view across the concourse. Glazed areas are integrated with the pattern of ribs.

This de-materialisation is both a denial and a release. Weight vanishes and the mass hovers. Like the underbelly of some flying saucer the canopy floats. It is a trick of the light.[9]

The railway station at Satolas Airport, Lyons, is the final example where structure defines the extent of penetrations for natural light. Two rows of skylights run the length of the train platforms. Each diamond-shaped area of glazing reflects the geometrical pattern of the underlying structural ribs (Figs 8.9 and 8.10) In section, structure reads as a series of portal frames, but not of the type found in most buildings. Each frame, skewed to the main axis, expresses a sense of lightness and elegance with its outwardly inclined columns and cambered beams. The intersections and bifurcations of the frames create the attractive and flowing skeletal framework into which the skylights are so well integrated.

The Satolas Airport structure also integrates artificial lighting effectively – in a far more sophisticated manner than merely providing a means of support for surface-mounted or hung light-fittings. Lights that illuminate the ribs soaring over the outer two station platforms are recessed within sculptured stub-columns (Fig. 8.11). Located between the perimeter diagonal struts and the roof ribs the lighting details recall Calatrava's similar but less ghoulish integration of structure and artificial light at the Stadelhofen Railway Station, Zürich. At several locations in the underground mall, the light sockets that are recessed into rounded concave concrete surfaces read as tear-drops (Fig. 8.12). The floor structure above the lights is treated just as sensitively by being pared back to elegant tapering ribs with glass-block pavers admitting natural light.

▲ **8.11** Recessed lights in stub columns.

▲ **8.12** Stadelhofen Railway Station, Zürich, Switzerland, Santiago Calatrava, 1990. Integration of structure and artificial lighting.

Maximizing light

Where requiring high levels of daylight or transparency through the building skin, architects adopt a number of stances towards structural detailing. Maximum daylight implies reducing the silhouette or shadow of structural members. The two most common methods are either to minimize structural member sizes, or to penetrate typically sized members. Transparent structural members are also becoming increasingly popular.

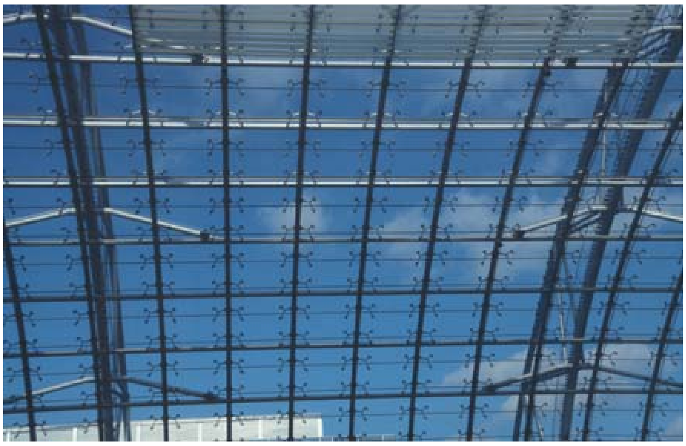
Detailing to minimize structural size

Chapter 7 discusses how the dual architectural qualities of complexity and lightness can arise where structural dimensions are minimized. Simple calculations show that if one tension rod is replaced by two smaller diameter rods with a combined strength equal to the original, the area of the structural silhouette is reduced by approximately 30 per cent. With four rods this reduction in silhouette reaches 50 per cent – the more members, the more light, but also more visual complexity.

At 237 m long, 79 m wide and 28 m high, the vaulted Trade Fair Glass Hall, Leipzig, was the largest single-volume glass building of the twentieth century. The tubular steel exoskeletal structure consists of ten primary trusses that stabilize a grid-shell (Figs 8.13 and 8.14). Triangular in cross-section, the arched trusses are fabricated from relatively small-diameter steel tubes whose varied wall thicknesses reflect the intensity of the structural actions. A resolute strategy to achieve maximum transparency excluded potentially large-scale members from consideration. As Ian Ritchie, project architect, explains:

> *Transparency was a key design objective. We wanted to minimize the structural silhouette, and in fact the total area covered by structure in any*

▲ **8.13** Trade Fair Glass Hall, Leipzig, Germany, Ian Ritchie Architects, 1996. Exterior trusses support the vaulted grid-shell.



▲ **8.14** Trusses and the grid-shell as seen from within the hall.

▲ **8.15** Cité des Sciences et de l'Industrie, Paris, France, Adrien Fainsilber, 1986. Les Serres or conservatories on the main façade.

▲ **8.16** A hierarchy of prestressed cable-beams resist face-loads on the glazed walls.

radial view met our adopted criterion of no more than 15 per cent. (This percentage arrived at by analyzing many of the glass structures we have designed, represents the maximum interference which allows the overall design to have a strong feeling of lightness.)[10]

Even though completed back in 1986, the three glazed conservatories known as Les Serres on the southern façade of the Cité des Sciences et de l'Industrie, Paris, still represent a fine example of structure designed to maximize light (Figs 8.15 and 8.16). Finely detailed horizontal cable-beam girts span 8 m between vertical steel posts to support face-loads acting on the 2 m square glass panels. An enlarged version of the girts transfers horizontal loads from the intermediate vertical posts to each side of the 32 m wide bays. Prestressing the catenary cables to limit the number of structural members acting in compression has enabled this

▲ **8.17** School at Waidhausenstraße, Vienna, Austria, Helmut Richter, 1995. Composite steel walkway beams.

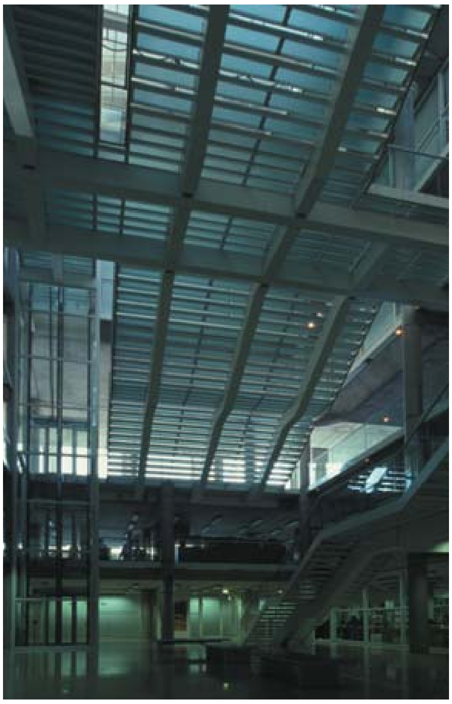
▲ **8.18** Triangular cantilever trusses support the mono-slope glazed roof.

type of detailing to approach the limit of achievable transparency. Glass plays an important structural function by supporting its own weight, hanging from the uppermost tubular steel beams. The transparency of the system is described by one author:

> *The tension trusses sit some distance behind the plane of the glass, and the connections to the glass are so light that they seem almost not to touch the glass. This fact, and the lightness of the tension supporting structure, enhance the feeling of transparency which Fainsilber [the architect] was so keen to achieve. The resulting structure is light and almost ephemeral: the boundary between inside and out is sensitively and lightly defined.*[11]

Although not pushing technological boundaries as hard as at Les Serres, the School at Waidhausenstraße, Vienna, also exemplifies structural detailing that maximizes daylight. A fully glazed circulation spine and two halls, one for assembly and another for sports, link the southern ends of three conventional concrete classroom blocks. Glazed mono-slope roofs rise from the ground floor to enclose the halls and the four-storeyed walkways. Walkway beams of composite construction reduces individual structural member sizes to small I-section beams acting as compression chords and steel rods below them resist the tension component of the bending moments (Fig. 8.17). The assembly hall roof structure cantilevers from a rigid support base to the roof of the classroom blocks. In this case structural lightness is a consequence of generously deep three-dimensional trusses and their relatively fine steel-tube members (Fig. 8.18).

The Carré d'Art, Nîmes, is the final example of detailing that minimizes structural size to maximize light. In order to respect the height of the



▲ **8.19** Carré d'Art, Nîmes, France, Sir Norman Foster and Partners, 1993. Glass stair-treads and the supporting structure in the atrium.

▲ **8.20** Bevelled and set-back beams.

surrounding buildings in its historic city, half the library and contemporary art museum is built below ground. Although the lower three basement floors are not daylit, a six-storey central atrium allows natural light to reach deep inside the building. The problem of channelling light through a space containing the main stairway system is solved by the choice of glass stair-treads (Fig. 8.19). As one reviewer comments: 'The purpose of the glass staircases becomes clear in descent to the lower levels. Daylight transforms what would otherwise have been a gloomy pit into a magical grotto. It is like standing under a waterfall.'[12]

Having successfully brought light down into the atrium, as much light as possible needs to be moved horizontally into the surrounding spaces. In this situation structural detailing enhances this process, more by modifying structural configuration than by reducing structural size. In order to maintain planar concrete ceiling soffits, up-stand beams span between columns. The difference in depth between the beams and slabs creates a space for services under the raised-floors. Where the beams on each storey frame the perimeter of the atrium and also the perimeter walls, they are off-set from the columns in plan, and their sides facing the light are bevelled (Fig. 8.20). This arrangement not only visually slims the floor system, but more importantly, significantly increases the quantity of daylight entering interior spaces.

Penetrations in structural members

Although penetrations through structural members are normally considered aspects of structural detailing and could have been discussed in the previous section of this chapter, such a common and significant response to the need for daylight warrants specific discussion.

Before considering several contemporary examples, two cases of historical interest deserve mention – first, Henri Labrouste's stackroom at the Bibliothèque Nationale, Paris. Giedion describes the highly penetrated floors that are located under a glazed roof:

> *Cast-iron floor plates in a gridiron pattern permit the daylight to penetrate the stacks from top to bottom. Floor plates of this open design seem to have been used first in the engine rooms of steamships … Nevertheless, observing them in our day, we recognize in the manner in which light penetrates the grillwork of the iron floor the germ of new artistic possibilities.*[13]

Since the popularity of stiletto-heeled shoes, steel-grating floors have limited applications, but as observed at the Carré d'Art, glass flooring is now a well established substitute.

The other notable historical example of light-enhancing structural penetrations occurs in Frank Lloyd Wright's Usonian House, Mount

▲ **8.21** Schools of Geography and Engineering, Marne-la-Vallée, Paris, France, Chaix & Morel, 1996. A finely perforated web of a steel beam.

▲ **8.22** Mexican Embassy, Berlin, Germany, González de León and Serrano, 2000. A penetrated circular wall forms part of the atrium.

Vernon. Concrete blocks, L-shaped in plan, are placed and stacked vertically to form U-shaped columns. Both faces of blocks on one side of the U are penetrated and glazed. Objects displayed on glass shelves within the column are illuminated by daylight.[14]

Returning to contemporary examples of structural penetrations maximizing light, the United Airlines Terminal is revisited (see Fig. 7.12). Circular penetrations through beam webs appear to contribute to its well-lit spaces, but given that the lighting designer does not mention them in his lighting strategy, their contribution to the overall lighting levels is probably quite low.[15] At the Schools of Geography and Engineering, Marne-la-Vallée, webs of steel beams are perforated by small diameter holes (Fig. 8.21 and see Fig. 3.49). This method that introduces light through steel sections is likely to be more widely exploited in the future due to its greater subtlety. But as at the United Airlines Terminal, its true value might lie in making the structure *appear* lighter rather than increasing measurably the intensity of daylight.

Windows invariably penetrate concrete structural walls, but smaller and more numerous penetrations may be appropriate when daylight rather than views is sought. A circular atrium sits behind the striking façade of the Mexican Embassy, Berlin, its exterior wall essentially a partial concrete drum (Fig. 8.22 and see Fig. 4.19). 'Capped by a massive

▲ **8.23** Broadfield House Glass Museum, West Midlands, England, Design Antenna, 1994. Interior of the glass extension.

skylight and punctured on its curved walls by cylindrical portholes, the drum is all about natural light. It evokes the "lightness" of concrete, its dual character, simultaneously delicate and weighty.'[16]

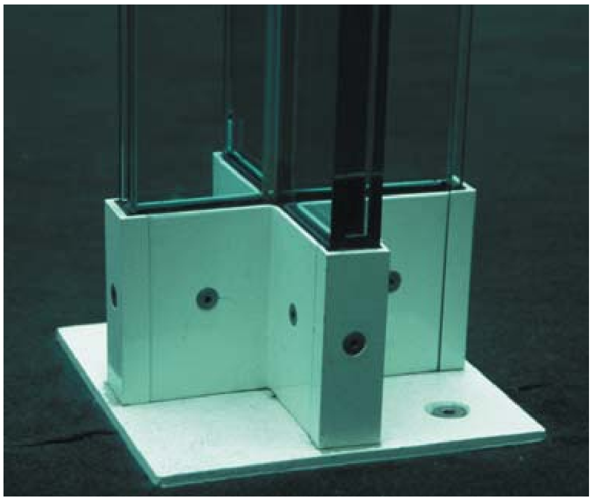
Transparent structure

Secondary and tertiary transparent structural elements in the form of glass window mullions and glass blocks have been used for many years. The Sainsbury Centre for Visual Arts, Norwich, with its full-height glass mullions, was completed in 1977 (see Fig. 5.7). However, only recently have designers' improved knowledge of glass technology led to glass undertaking primary structural roles. Although glass is currently the preferred transparent structural material, no doubt alternative materials will be developed in the future.

A lean-to extension at Broadfield House Glass Museum, West Midlands, relies entirely upon glass structural elements (Fig. 8.23). Laminated glass plates form vertical posts to glazed walls and support glass rafters at glued mortice and tenon joints.[17] Wall and roof glazing provides in-plane bracing resistance.

In the Town Administrative Centre, Saint-Germaine-en-Laye, Paris, in what is considered a world-first, laminated glass columns designed for an axial load of 6 tonnes, support the atrium roof beams (Figs 8.24 and 8.25). The columns, cruciform in section, possess a greenish hue. Any greater degree of transparency would render them almost invisible and therefore hazardous to building users. In this public space the columns delineate circulation and waiting areas from staff workstations. The structure subdivides and orders space without reducing visibility and security significantly. The columns obstruct daylight passing through the glazed walls

▲ **8.24** Town Administrative Centre, Saint-Germaine-en-Laye, Paris, France, Brunet and Saunier, 1995. Glass columns support roof beams.



▲ **8.25** A glass column base detail.

▲ **8.26** Apple Store, New York, USA, Bohlin Cywinski Jackson, 2002. The central glass staircase.

of an internal garden slightly, but such a potentially small shadow effect is of no consequence given the transparent roof. Excessive glare and thermal gain are likely to be far more serious problems.

During the conversion and refurbishment of a 1920s post office into the Apple Store, New York, the architects maximized lightness, transparency and a sense of spaciousness with the provision of a central glass staircase supported by glass load-bearing walls (Fig. 8.26). The space under the stair remains a void except for the glass fins that provide transverse stability and enhance the vertical load-carrying capacity of the glass walls. Below the levels of the stair treads the wall thickness comprises three layers of glass. Two laminated panes support the handrail. The glass landing and stair treads are laminated from four layers of glass. Elegant circular stainless steel fixings connect the glass panes together to achieve a truly transparent structure (Fig. 8.27).

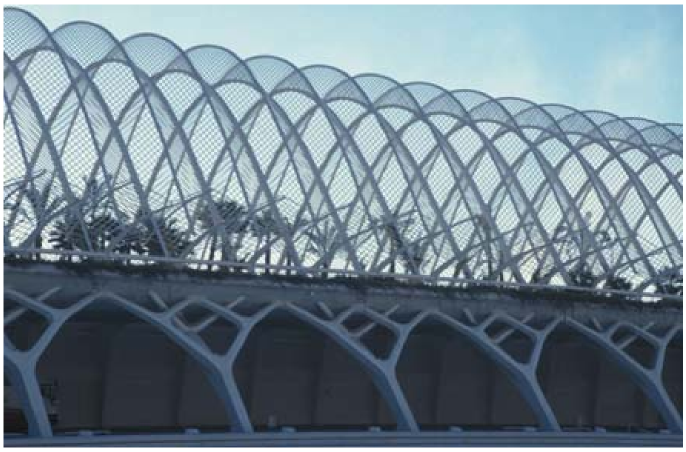
Modifier of light

Not only does structure act as a source of light and is frequently designed to maximize the quantity of light entering a building, it also modifies the intensity and quantity of light. As well as excluding or blocking light by virtue of its opaqueness, structure also filters and reflects light.

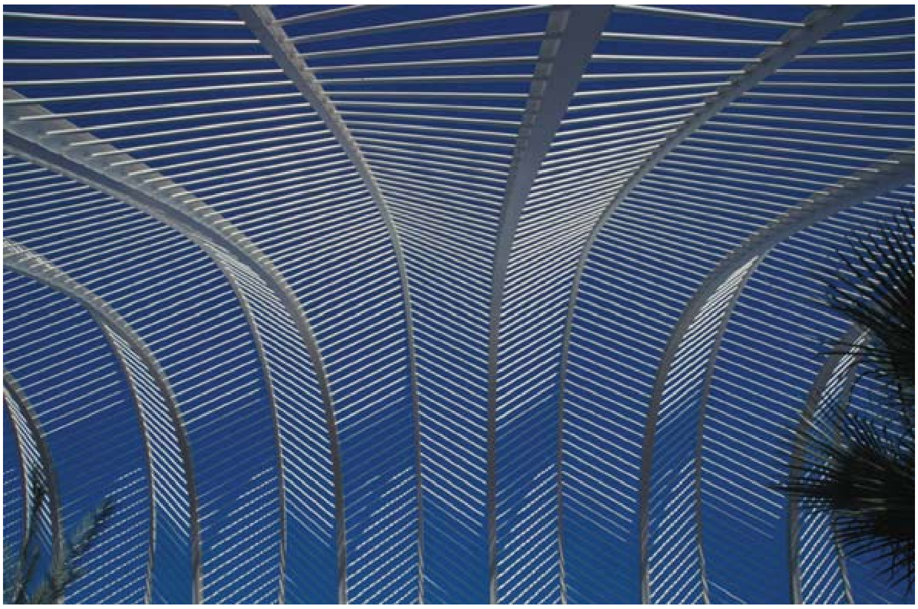
Filtering

Numerous closely spaced and often layered structural members filter light. Where structural layout and density evoke the trees of a forest, as in the Oxford University Museum Courtyard, daylight is experienced as if filtered through a canopy of tree branches (see Fig. 6.39).

▲ **8.27** Stair treads connect to the glass wall.



▲ **8.28** City of Arts and Sciences, Valencia, Spain, Santiago Calatrava, 1998. L'Umbracle with its garden shade-structure.

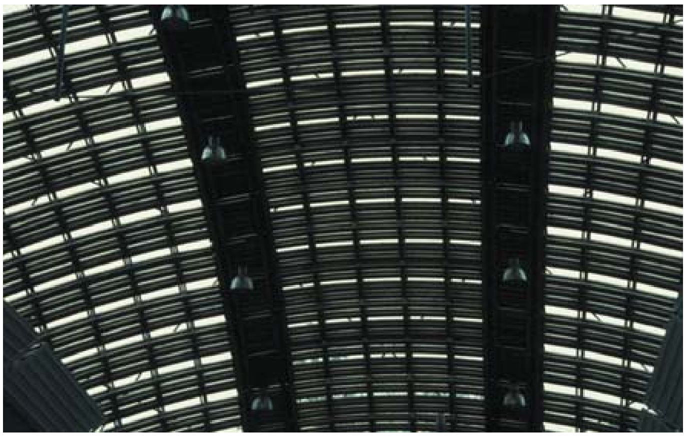


▲ **8.29** Shade-structure arches and ribs.

Roof structure within the Wohlen High School auditorium also plays a strong light-filtering role (see Figs 6.18 and 6.19). Daylight enters the hall through clerestory windows above the interior structure. The closely spaced ribs that radiate from the primary arches act as light filters. A white-stained finish increases the timber's reflectance under both natural and artificial lighting conditions.

Santiago Calatrava's fascination with ribbed structures also finds expression in an exterior structure known as L'Umbracle, in the City of Arts and Sciences precinct, Valencia (Figs 8.28 and 8.29). As well as

▲ **8.30** Seed House and Forestry Centre, Marche-en-Femenne, Belgium, Samyn et Associés, 1996. Exterior view.



▲ **8.31** Shading increases at the splice positions of the transverse arches.

enclosing car parking at ground level, the roof of L'Umbracle functions as a tree-lined garden. An arched and ribbed shade-structure encloses the whole area, and while its ribs are more slender and spaced further apart than those at Wohlen High School, one strongly experiences its light-filtering qualities. Plants growing over the ribs in some areas increase the level of shading.

The interior structure of the Seed House and Forestry Centre, Marche-en-Femenne, also filters light and provides shade (Figs 8.30 and 8.31). Bentwood arches that span the building width support the completely glazed ovoid form. Longitudinal arches provide stability in the orthogonal direction. The combination of closely spaced arches and 100 mm wide members leads to significant areas of shade, especially where the timbers are lap-spliced. Strong striped patterns of sunlight and shadow enliven the interior spaces.

Reflecting

Structural members screen direct sunlight but also provide surfaces off which it may reflect and then diffuse into surrounding space. The deep atrium beams of Louis Khan's Philip Exeter Library, Exeter, already mentioned in this chapter, exemplify this interaction between structure and light even though some commentators have queried whether the beams achieve sufficiently high light levels at the ground floor level in the atrium. They point to the small quantity of direct light admitted through the partially shaded clerestory windows, and the low reflectivity of the grey concrete beams.

Roof beams in the Mönchengladbach Museum receive significantly more direct light and, also due to their lighter colour, play a more influential

▲ **8.32** Mönchengladbach Museum, Germany, Hans Hollein, 1982. Beams screen and reflect light into the gallery below.

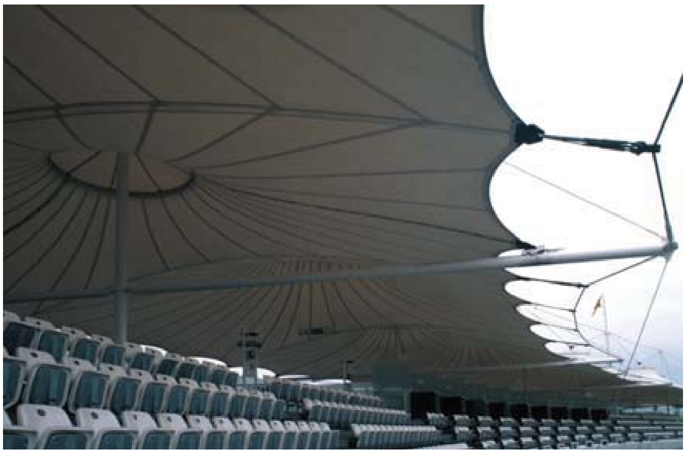
▲ **8.33** Business School, Öhringen, Germany, Günter Behnisch & Partner, 1993. A primary beam with the skylight above and the roof below.

role in screening sunlight and reflecting it into the gallery (Fig. 8.32). A similar approach is taken in the Business School gymnasium, Öhringen (Fig. 8.33). The white-stained glue-laminated beams that span the width of the hall reflect rather than screen light. North-facing translucent glazing slopes from a lowered ceiling and up and over the beams that project above the roof line. Their raised location with respect to the roof eliminates any possibility of their screening direct sunlight at the end of a day when the sun's rays are almost horizontal, but the reflectivity of the beams increases the effective width of the glazed roof areas and therefore the intensity of illumination within the gymnasium.

Surfaces of structural members also provide opportunities for reflecting artificial light. The Vancouver Public Library, Vancouver, is typical of many buildings where a comfortable level of background lighting is reflected from suspended floor soffits (Fig. 8.34 and see Fig. 3.1). Uplights illuminate the vaulted concrete slabs whose shallow coved surfaces are well suited to achieving appropriate levels of indirect and diffuse light.

Fabric structures are well known for their ability to reflect and diffuse light. Their conventional white coloured and shiny surfaces (dark fabrics are prone to severe solar overheating) guarantee a high degree of reflectivity which responds well to uplighting. The ability of the fabric to diffuse light is best experienced on a sunny day. Fabric translucency that

▲ **8.34** Library Square, Vancouver, Canada, Moshe Safdie and Associates Inc., 1995. An uplit vaulted ceiling.



▲ **8.35** Mound Stand, Lord's Cricket Ground, London, England, Michael Hopkins and Partners, 1987. Underside of the fabric roof.

varies according to thickness and the type of fabric provides relatively low-intensity light that is even and soft. The Mound Stand, London, is a typical example (Fig. 8.35). Although the PVC-coated polyester fabric primarily provides shade, a pleasant quality of diffuse light filtering through the canopy is also noticeable.

Modified by light

Although structure often controls light – its intensity and quality – the relationship between structure and light is not entirely dominated by structure. For light not only reveals structure, but also modifies one's perceptions of it. Millet explains how in two churches of very different character, one Bavarian rococo and the other contemporary North American, glare from relatively intense and well-controlled daylight dematerializes their structures and has structural members perceived as luminous lines.[18]

Dematerialization occurs where an area of structure that is illuminated far more intensely than the surrounding ambient light levels seems to disappear or at least loses its sharpness of definition in the bright haze. For example, the lengths of columns that pass through a window display-case in the Timber Showroom, Hergatz, are so brightly illuminated when exposed to strong sunlight that they merge into the glary background (Fig. 8.36 and see Fig. 5.6). The columns therefore read as not being grounded. They appear to stop above the window opening, thereby increasing the visual complexity and interest of the building. It is unlikely that this visual effect, which may go unnoticed on a dull day, was intended by the designers whose focus of attention would have been the provision of adequate fenestration to display the company's products. A similar

▲ **8.36** Timber Showroom, Hergatz, Germany, Baumschläger-Eberle, 1995. Glare dematerializes the base of the portal legs. They appear to terminate at the top of the display window.

effect is observed at Saint Benedict Chapel, Sumvtg (see Fig. 6.4). Where interior posts pass in front of the clerestory, glare from their surfaces reduces their clarity and the starkness of their silhouettes against the sky, and intensifies the perception of the roof floating.

Intentional dematerialization of structure by light characterizes the work of the contemporary architect Juan Navarro Baldweg. According to one reviewer, Baldweg develops the theme of light and structure in a completely new way:

> *Here light prevails over shade, homogeneity over contrast. A diffuse and even light that descends from above can be obtained by removing every last trace of shadow: thus the roof is transformed into a combined system of V-shaped girders and skylights, becoming a luminous mechanism … Just as the girders are given a triangular cross-section to eliminate every remaining cone of shade, so to the pillars acquire a triangular section, so as to obtain, through the play of light, an effect of dematerialization of the wall.*[19]

The combination of structure and artificial lighting can also be used to considerable aesthetic effect in both exterior and interior situations. For example, the ground floor exterior columns of 88 Wood Street, London are singled out for illumination by down-lighting, that at night, transforms them into cylinders of light (see Fig. 4.4). Illumination of the Tokyo International Forum exposed interior roof structure produces a

▲ **8.37** Mönchengladbach Museum, Germany, Hans Hollein, 1982. Geometrical patterns of light subvert the sense of inhabiting an orthogonal structural grid.

considerably more dramatic effect: 'At night, light reflecting off the surface of the roof truss ribs transforms the structure into a monolithic floating light source illuminating the glass hall and assuring the visual presence of the building in the Tokyo skyline.'[20]

In the final example where structure appears to be modified by light, light disrupts the perception of an orthogonal structural layout. At the Mönchengladbach Museum, an approximately 6 m square column-grid is imposed upon the irregular-shaped main gallery. Rather than visually reinforcing the grid geometry by means of beams or other elements, lines of artificial lighting achieve the opposite effect. Lengths of fluorescent tubes that are surface-mounted on the plain ceiling create polygonal patterns of light that break down one's perception of inhabiting a grid (Fig. 8.37). Drawn to the light, the eye follows the lines of brightness. Their patterning provides a welcome visual alternative to that of the orthogonal structural layout.

Summary

Structure and light are both indispensable and interdependent elements of architecture. While structure may control light – its locations of entry into a building and its quantity and quality, the need for daylight inevitably determines structural form and detailing. Although during the design process structural decisions may be subservient to those concerning light, once built, roles reverse and structure controls light.

After acknowledging Louis Kahn's innovative integration of structure and light, the chapter explores how open structure can act as a source for light to enter a building. Structural form, members and even structural connections all participate in this role. Readers are also reminded of how structural layout often delineates the shapes of transparent areas in the exterior skins of buildings.

The integration of structure and both transparency and the ingress of daylight is achieved by a variety of approaches. These include detailing structure with more smaller rather than fewer larger members, penetrating solid structural members to 'lighten' them, and using glass or translucent structural members.

Since sunlight is unwelcome in certain spaces, structure plays light-modifying roles. Structure filters and reflects, producing even and diffuse qualities of light. Finally, examples illustrate how light modifies one's perception of structure. Light dematerializes structure, has structure read primarily as a source of light, and subverts awareness of structural rationality.

REFERENCES AND NOTES

1 Meiss, P. van (1990). *Elements of Architecture: From Form to Place*. Presses Polytechniques Romandes, p. 121.
2 Millet, M. S. (1996). *Light Revealing Architecture*. Van Nostrand Reinhold, p. 60.
3 Tyng, A. (1984). *Beginnings: Louis I. Kahn's Philosophy of Architecture*. John Wiley & Sons, p. 145.
4 Tyng (1984), p. 146.
5 Comments by Louis Kahn compiled in Johnson, N. E. (1975). *Light is the Theme: Louis I. Kahn and the Kimbell Art Museum*. Kimbell Art Foundation, p. 21.
6 Dimond, R. and Wang, W. (eds) (1995). *On Continuity*. 9H Publications, p. 188.
7 Ron W. (ed.) (2002). *CASE: Toyo Ito Sendai Mediatheque*. Prestel.
8 For a pictorial explanation of the construction sequence see Branch, M. A. (1991). Internationally styled. *Progressive Architecture*, 72 (4), pp. 87–93.
9 Balmond, C. (2002). *informal*. Prestel, p. 316.
10 Ritchie, I. (1997). *The Biggest Glass Palace in the World.* Ellipsis London Ltd, p. 34.
11 Brown, A. (2000). *The Engineer's Contribution to Contemporary Architecture: Peter Rice*. Thomas Telford Ltd, p. 73.
12 Davies, C. (1993). Norman Foster. *Architecture*, Sept., pp. 106–9.
13 Giedion, S. (1978). *Space, Time and Architecture*, 5th edn. Harvard University Press, p. 224.
14 Millet (1996), p. 63.

15 Shemitz, S. R. (1987). Lighting the way. *Architectural Record*, 175 (13), pp. 148–155.
16 Bussel, A. (2001). Great expectations. *Interior Design*, 72 (7), pp. 297–301.
17 For construction details refer to Dawson, S. (1995) Glass as skin and structure. *The Architects' Journal*, 210 (10), pp. 32–4.
18 Millet (1996), p. 66.
19 Zardini, M. (1998). Light and structure in Juan Navarro Baldweg's work. *Lotus International 98*, p. 56–9.
20 Toy, M. (ed.) (1997). Light in architecture. *Architectural Design Profile 126*. John Wiley & Sons, p. 43.