6

Interior structure

Introduction

Inevitably, some overlap occurs between the previous chapter, which explored the relationships between interior structure and building function, and this chapter. Chapter 5 examined how structure subdivides space in order to physically separate different functions and accommodate them in their own spaces, and how it defines and identifies other important functions, such as circulation. This chapter, however, is not concerned about how structure affects building function in a practical or physical sense – rather, it considers how structure contributes to the architectural qualities and characters of interior spaces.

Many architects believe that there is far more to the relationship between structure and building function than merely meeting physical spatial requirements. If the design approach of Peter Cook is typical, these practical needs are almost taken as given, in order that the real architectural challenge can begin.[1] Cook develops the structural strategy of a building by first designing the 'primary elements'. This means adopting a certain structural concept such as the use of a structural spine, be it a wall or a corridor of columns. As the issue of integrating structure with function is not raised explicitly, it can be assumed the need for fully functional spaces has been attended to during the development of the structural concept. He then turns his attention to 'secondary elements', by which he means individual structural members like beams and columns. Before deciding how to design them, he asks a series of questions: 'Is it a highly rhetorical building with a rhetorical structure? Is the structure to be the muted element? Is the aim for lightness or for a certain emphasis of presence that may contrast with another part of the building? Is the roof to be 'read' as one or do we want the interval of the elements to be staccato, busy, cosy or symbolic of technicality?'[2]

These questions that suggest but a few of the possibilities that this chapter explores, acknowledge the potential for exposed structure to enrich interior architecture visually and conceptually. The extent to which this occurs depends on a variety of factors. Where structural members contrast with adjacent surfaces or architectural elements by means of colour, materiality, depth or texture, structural exposure is heightened. For example, naturally finished timber members stand out against a light-coloured background. Sometimes exposed structural elements may not even be perceived as structure if they are unusually shaped, or if they are visually undifferentiated from other non-structural elements, like partition walls. The effectiveness of any degree of structural exposure must be evaluated in terms of how the exposure, or lack of it, contributes architecturally. Visual exposure of structure, if at all, must enhance the design concept and result in compelling and coherent architecture. After all, although bland and monotonous interior environments are required in some instances, such as to achieve a necessary standard of hygiene, they are not generally conducive to human habitation, and are usually an anathema to architects.

As for the content of this chapter, the next section illustrates how structure enlivens interior surfaces. Structure makes similar contributions inside buildings as it does to exterior building surfaces (Chapter 3), such as modulating, patterning and providing texture. The chapter then continues with examples of interior space enhancement by spatial rather than surface deployment of structure. In some buildings, structure encourages habitation by its density and small-scaled members. In others, large sized structural members might tend to overwhelm occupants. It is noted how structure orders plans, creates spatial hierarchy, introduces visual diversity and injects a sense of dynamism into a space. Finally, the expressive potential of interior structure is examined. Examples include structure expressing a wide diversity of ideas and responding to such issues as site, building function and geometry.

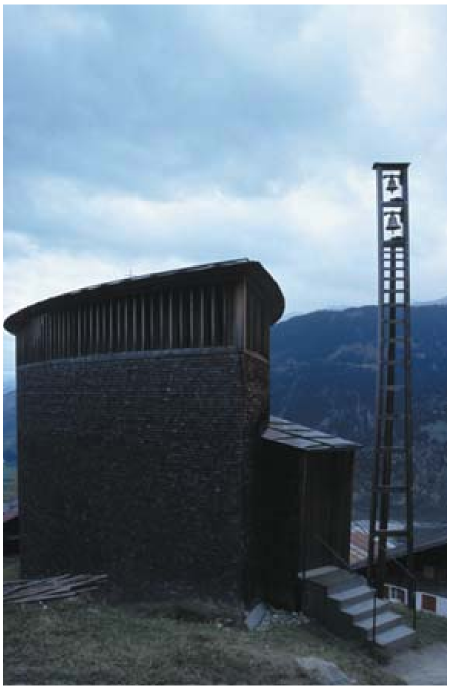
Surface structure

This section illustrates how interior exposed structure contributes architecturally by modulating and texturing surfaces. Any interior structure that is connected to, or positioned immediately adjacent to the building skin, is considered surface structure.

In contrast to most exterior structural elements, the interior exposed structure considered in this book, particularly in low-rise construction, is more likely to consist of timber than any other structural material. Without having to contend with potentially destructive sunlight and moisture, timber members and their connections are well suited to interior conditions. Consider one of the four roof structures Calatrava designed as set-pieces for the Wohlen High School. The roof covers a squat drum at the centre of the school entrance foyer (Fig. 6.1). The structure is conceptually simple. Sloping rafters radiate from a supporting concrete ring beam to prop a central lantern. However, articulation

▲ **6.1** Entrance foyer roof, Wohlen High School, Switzerland, Santiago Calatrava, 1988. Attractive structural roof framing pattern.

▲ **6.2** Refined timber struts connect to the steel rod tension-ring and the rafters with deepened ends.



▲ **6.3** Saint Benedict Chapel, Sumvtg, Switzerland, Peter Zumthor, 1989. Chapel exterior.

of different structural actions introduces a constructional and visual complexity that modulates the interior roof surface and forms a most attractive pattern.

Calatrava has separated two of the structural functions performed by the rafters – that of propping the lantern and the central area of the roof, and secondly, transferring the roof weight to each end of the rafters by bending and shear. Timber spindle-shaped struts perform the propping duties. They fit into conical steel shoes, which at the lower ends of the rafters connect to two elements, the ends of the V-shaped rafters themselves and a circumferential tension-ring consisting of three steel rods (Fig. 6.2). The tension-ring absorbs the horizontal component of strut thrusts while the vertical component is transferred upwards through the deep end-sections of the glue-laminated rafters. They load short steel stub-columns that bear on the surrounding ring beam and provide enough height for a short circular clerestory drum. The entry of natural light, restricted to the glazed lantern and the clerestory, accentuates the radiating pattern of the structure. The petal-shaped roof soffit surfaces and the structure below them are reminiscent of a flower head.

Saint Benedict Chapel, Sumvtg, offers another very attractive example of interior surface modulation. In this case, structure graces both the roof and the walls. Situated on the steep slope of an alpine valley, the chapel is tear-drop or leaf-shaped in plan. Outside, curved timber shingle-clad walls rise to a horizontal glazed and vertically louvred band below the shallow roof. Given the absence of visible support to the roof, it appears disconnected from the enclosing wall below and 'hovers' (Fig. 6.3).

▲ **6.4** Chapel interior, facing towards the altar.

Inside the chapel, the roof support is revealed. Thirty-six regularly spaced square posts are set out from the interior plywood wall-lining (Fig. 6.4). Each connects delicately to the wall by three steel pins. The simple move of withdrawing the posts from their conventional location within the walls and exposing them affects the interior enormously. Acting as visual markers, they modulate the wall surface, but also increase the shape definition of the interior space and accentuate a sense of enclosure by their continuous alignment with the roof ribs they support.

▲ **6.5** Ribbed roof structure.

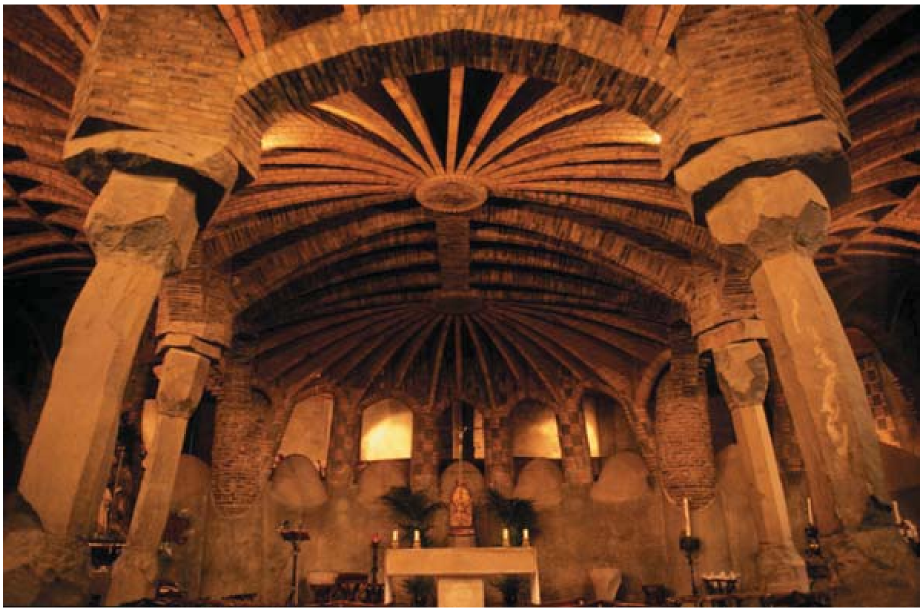
The roof structure possesses symmetry and visual simplicity. The ribbed pattern of rafters recalls the ribs on the underside of a leaf (Fig. 6.5). Whereas conventional roof framing usually comprises a hierarchical structure consisting of transverse rafters above a deeper longitudinal spine or ridge-beam, all the chapel roof ribs, including the spine-beam that does not span the whole length of the chapel, are of identical depth, and each branches from the spine to bear on a perimeter post. Thin steel plates, welded together to achieve the branching geometry, are interleaved between timber laminates to achieve a two-way structural action. Skilfully concealed, the reinforcement does not detract from the glue-laminated timber construction. Further evidence of detailing refinement is seen in the shape of the spine-beam itself. Not only trapezoidal in cross-section to soften its visual impact, its width tapers in harmony with the building plan, wide near the front of the chapel and narrow at the rear. These details that reflect the building form and the designer's aesthetic sensibility are indiscernible at the first viewing, but

▲ **6.6** FDA Laboratory, Irvine, California, USA, Zimmer Gunsul Frasca Partnership + HDR, 2003. The perimeter wall of the library with its internal buttresses.

contribute significantly to the simple beauty of the exquisite interior structure.

At the FDA Laboratory, Irvine, California, surface modulation is taken to another degree of intensity in the library. Not only does structure modulate the interior wall areas, but due to its considerable depth it also plays a spatial subdivisional role around the perimeter of the space. The library is semi-circular in plan, essentially enclosed within reinforced concrete walls. Supporting the ends of beams that radiate from the centre of the semi-circle, deep cast-in-place buttresses project into the room (Fig. 6.6). They subdivide the wall circumference into six equal segments, each of which has its own sense of partial enclosure. A desk placed in each segment benefits from natural light through a central slit window and a perimeter skylight above whose width matches the increased depth of the buttresses at roof level.

Ceiling structure, together with inclined columns, considerably enriches the interior space of the Güell Colony Crypt, Barcelona. Rough hewn stone columns, precisely angled in accordance with Gaudí's catenary analytical study, form an inner semi-circular arcade around the sanctuary.[3] This centralized structure focuses attention on the sanctuary and the particularly richly textured ceiling above it (Fig. 6.7). Shallow and audaciously thin brick arches support a brick soffit. The construction method, more common in timber than brick, has secondary members bearing on top of, rather than in the same plane as, the primary members.



▲ **6.7** Güell Colony Crypt, Barcelona, Spain, Antonio Gaudí, 1917. Columns support an inner arcade ring and the textured ceiling above.

Secondary ribs generally radiate toward the perimeter of the crypt from two circular nodes in front of the altar.

Westminster Lodge, Dorset, is one of several experimental timber buildings at Hooke Park that explores environmental architecture. It consists of eight single-bedrooms gathered around a central 8 m by 8 m living space. Roundwood thinnings, not normally considered of structural value, comprise its structure. Extensive research and development of pole-splices and other connection details confirmed the structural adequacy of this form of pole construction. After poles were spliced, they were bent to form a grillage of interlocking beams that span the main space and form the shallow curved roof (Fig. 6.8). The beams consist of two pole-chords spaced apart by timber blocks. Diagonal timber sarking that bears on the upper level of the poles, carries the weight of a turf roof.

Although exposed poles and lintels modulate the interior painted plasterboard walls and further express the roundwood framing system, the roof structure has a greater aesthetic presence in the interior space. The following factors combine to achieve a most visually satisfying roof structure – the close 600 mm grillage module, the gentle roof curvature that reflects the relative ease of bending small-diameter green poles, the depth and stratification of the five horizontal layers of structural members including the sarking, a level of structural complexity that can be comprehended, and finally, a natural peeled and trimmed pole finish.

▲ **6.8** Westminster Lodge, Hooke Park, Dorset, England, Edward Cullinan Architects, 1996. A grillage of roundwood beams spans the main space.

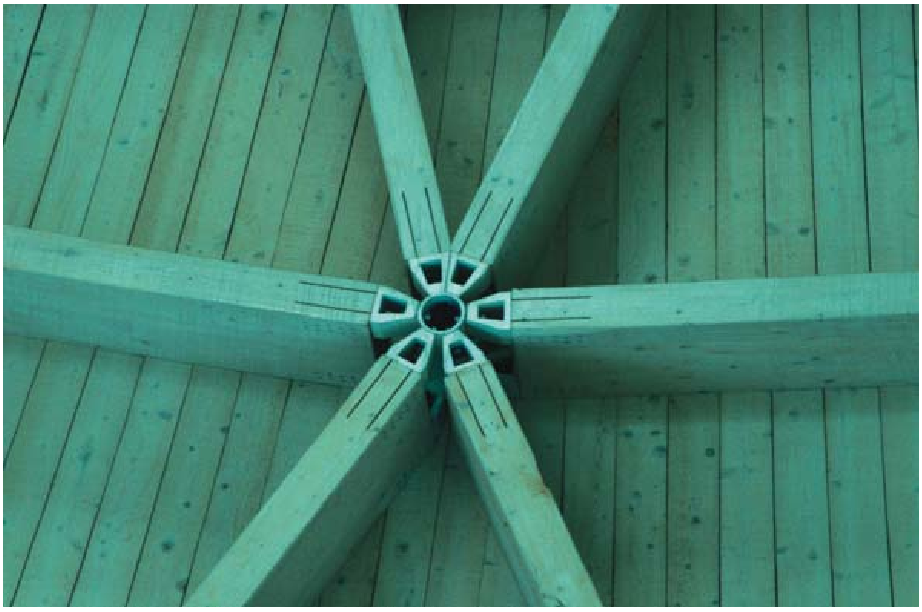
▲ **6.9** Building Industry School, Hamm, Germany, Heger Heger Schlieff, 1996. Lamella timber vaults span the workshop.

Exposed timber structure also enriches the interior surfaces of the next two buildings. As at Westminster Lodge, where structural form and materiality reflect a commitment to ecological sustainability, the timber roofs of the Building Industry School, Hamm, also possess a similar pedagogical value (Fig. 6.9). Seven timber lamella vaults that span between glue-laminated beams, roof the workshops. Four of the repeated vaults cover an interior hall-like volume while the other three shelter outdoor activities. Structure contributes a distinctive and attractive ceiling pattern to all the spaces.

Saint Massimiliano Kolbe church, Varese, exemplifies another building with aesthetically pleasing interior timber structure. Not only is the white hemispherical form in a northern Italian suburban setting unexpected, but so is its interior consisting of timber lining over a triangulated glue-laminated timber dome (Fig. 6.10). The primary triangulating ribs, the horizontal members between them and the lining are all stained white. The structural members, with their curved profiles, are sympathetic to the enclosing spherical geometry of the main congregational space and modulate its interior surface. Relative to the size of the enclosed volume, the small member sizes are a reminder of the structural efficiency of a braced dome.

Most of the connections between the timber members are concealed, but the architect has chosen to celebrate the joints between primary members (Fig. 6.11). The detail possesses similar qualities to Fay Jones' much admired Thorncrown Chapel connections where light passes through the timber joints.[4] Although the exterior cladding prohibits any

▲ **6.10** Saint Massimiliano Kolbe church, Varese, Italy, Justus Dahinden, 1994. Interior surface.



▲ **6.11** A typical joint between ribs.

transparency in the Varese church, the structural connections decorate the interior surface like a setting of widely spaced jewels. The architect has certainly achieved his aim of avoiding 'awe-inspiring and intimidating spaces . . . that make a totalitarian impression' and designed a space that is 'sheltering, protective and should inspire trust'.[5]

▲ **6.12** Sondica Airport Terminal, Bilbao, Spain, Santiago Calatrava, 2000. Ribs cantilever under the departure level forecourt.

For the final example of structure enlivening interior surfaces the new terminal at Sondica Airport, Bilbao, is visited. Huge cantilever ribs dominate the ground floor entry area while supporting the departure level forecourt and roading above (Fig. 6.12). From a maximum depth of approximately 3 m, the ribs taper towards their tips and merge with the concrete slab they support. They prepare visitors to the terminal for an architectural language of ribs within its interior.

▲ **6.13** Ribs radiate over the entire terminal ceiling.

In the main concourse, curved steel ribs radiate from the top of an inclined column to encompass the triangular plan of the whole space (Fig. 6.13). Part-way along their lengths the ribs are supported by a shallow steel arch, triangular in cross-section, which enhances the sweeping ribbed aesthetic. Structural ribs not only pattern the ceiling but also form all the window mullions, continuing the ribbed theme that dominates both the interior and exterior architecture of the terminal.

Although all the previous buildings exemplify attractive exposed structure it is worth cautioning the reader that surface structure, and in fact any exposed structure for that matter, may invite readings that are unintended by its designers. For example, a reviewer of the Great Court roof at the British Museum, London (see Fig. 3.55), observes:

> *From the ground, one is very aware of the geometric juxtapositions the roof makes with the existing forms in stone, particularly around the porticoes. Grids like this are by their nature non-hierarchical, but it is a Modernist fantasy that this means they are neutral. What the roof does is reinforce the*

impression that the Great Court is not a place to linger, but a space to move through; the swirling vortex of its geometry, which Buro Happold wrote its own software to resolve, is curiously restless from many angles of view.[6]

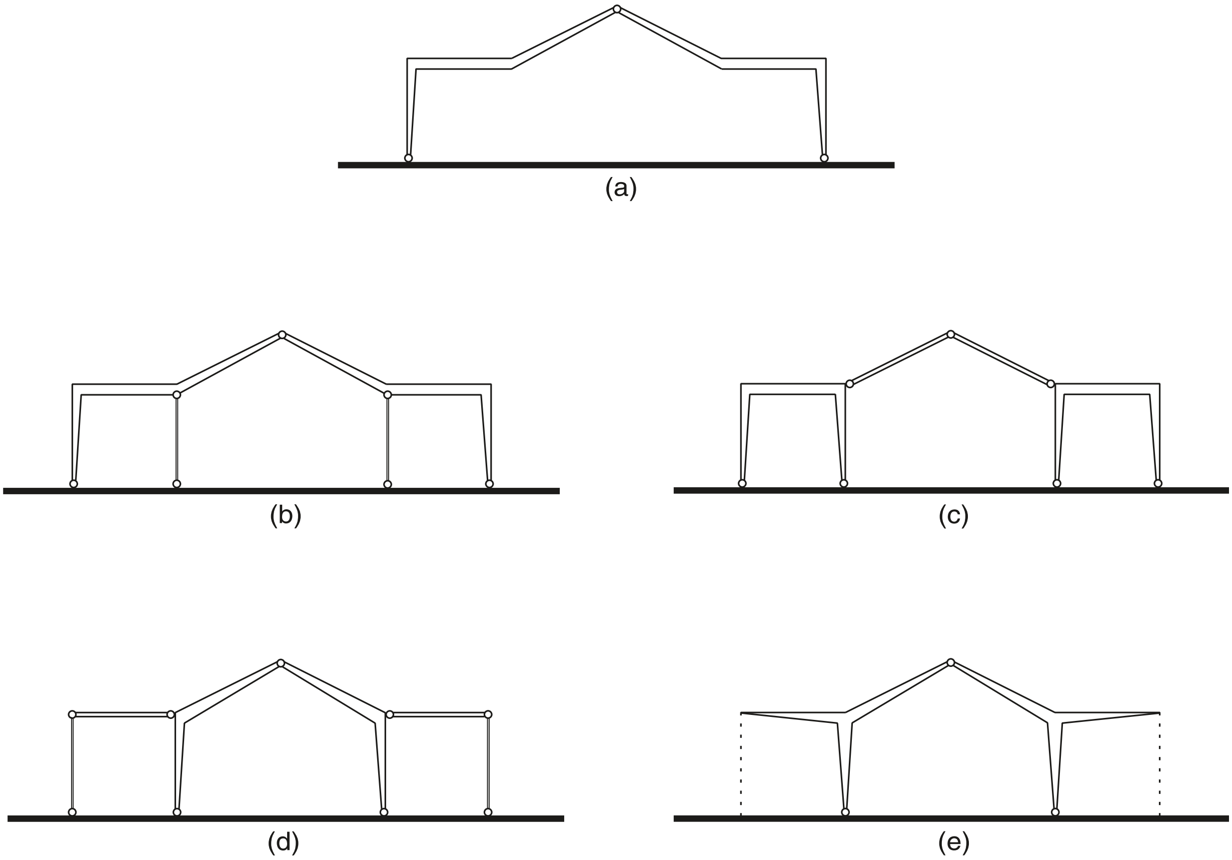
Although the architects did not intend to convey such a sense of restlessness, they would no doubt view this reading as a price to be paid for a scheme that roofs the courtyard in a most elegant manner.

Spatial structure

An underlying premise of this chapter is that spatial structure, such as a free-standing column, has a tangible impact upon the space around it. Ching explains this effect: 'when located within a defined volume of space, a column will generate a spatial field about itself and interact with the spatial enclosure', and 'when centered in a space, a column will assert itself as the center of the field and define equivalent zones of space between itself and the surrounding wall planes'.[7] But this is not to say that spatial structure contributes positively to the making of architectural space.

Consider, for example, free-plan column grids. Although they enhance constructability, they do not have the same effect on interior architecture. Such regular structural layouts are unlikely to be read positively. Van Miess expresses his concern: 'Some spaces have great difficulty becoming places. Let us take the example of the "neutral" spaces of large open-plan offices . . .' He continues by explaining how the Centraal Beheer office structure at Apeldoorn, *does* respond to the need for place-making (see Fig. 5.26).[8] Erickson, also critical of the free plan, writes: 'The open space grids of Mies and Corbu, for instance, are in retrospect both architectural and structural copouts as they do not respond directly to the particular spatial environments and have little to do with the genius of their architecture.'[9]

In spite of the architectural limitations of regular and rectilinear column grids, we must acknowledge the significant roles such structure does play in ordering space. Somewhat ironically, Centre Pompidou, Paris (see Fig. 4.18), a building with extensive floor-plate areas that offer almost unlimited planning flexibility, is criticized for its lack of ordering structure. A reviewer bemoans: 'It is even tempting to wonder if columns might have been an asset, or the interruption of circulation or fixed service cores – anything to impose some architectural discipline in the vast interior. . . . Yet it does seem that Piano & Rogers have played all their good cards on the highly expressive exterior of the building, leaving themselves not much with which to win our admiration inside.'[10] In

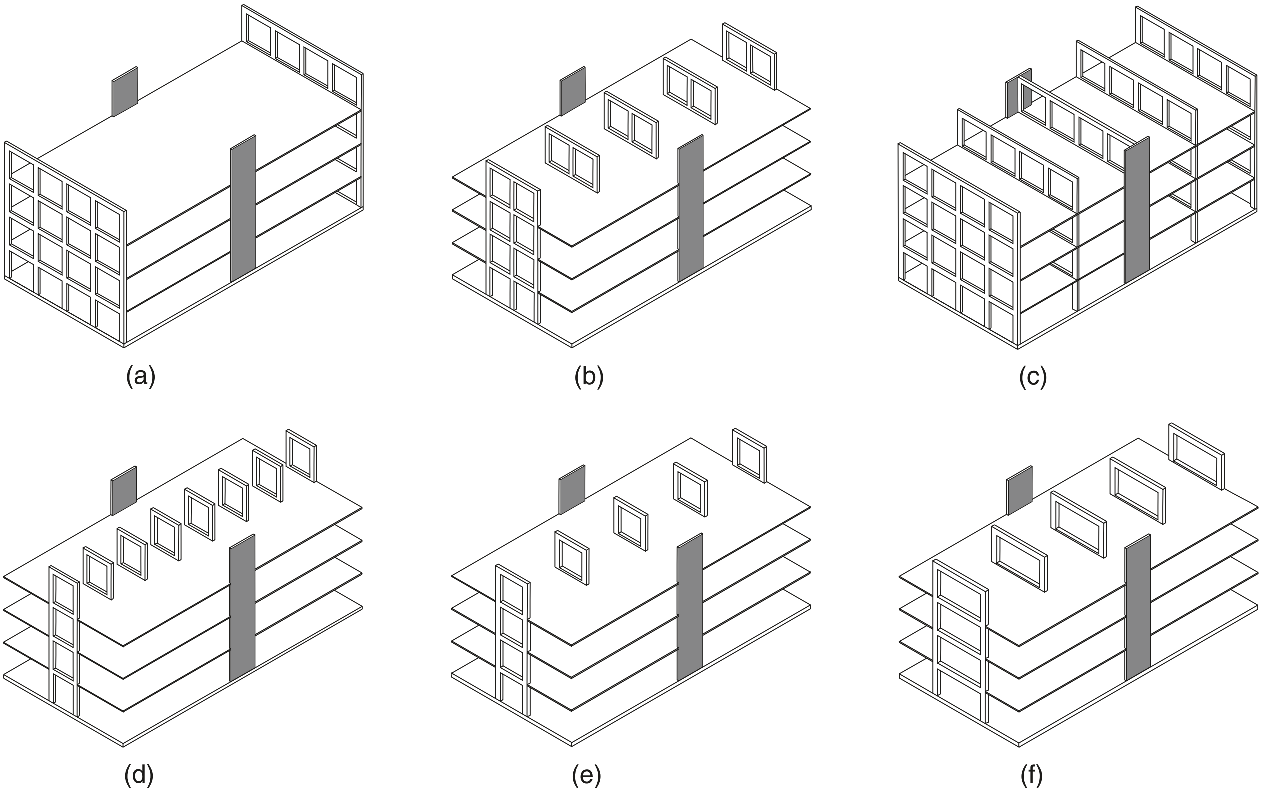


▲ **6.14** Different structural layouts affect how spaces are read. (After Ogg)

many buildings though, particularly those providing open-plan office accommodation, while column grids may be read optimistically as ordering space, they are more likely to be spatially disruptive.

The influence of spatial structure upon interior spaces of a building can be further appreciated by considering Fig. 6.14.[11] Within an identical building envelope very different spatial qualities arise by varying interior structural layouts, all of which are feasible from a structural engineering perspective. While the whole internal volume is essentially perceived as one space in options (a) and (b), (c) and (d) each provide two separate and differentiated spatial zones. Option (e) offers the opportunity of creating a closer relationship between the inside and outside.

A similar investigation of alternative structural layouts and their influence upon interior space can be, and should be performed on any building at the preliminary design stage. Figure 6.15 presents different lateral-load resisting layouts for a regular four-storey building. Variations to moment-resisting frames that resist transverse wind and earthquake



▲ **6.15** Alternative structural layouts for resisting transverse lateral loads on a multi-storey building.

loads only are shown. In each case the same two shear walls provide longitudinal stability. Gravity-only columns are not shown. As in the previous figure, each structural option contributes a unique spatial character to every floor that can strengthen the design intent. The six options are but just a taste of the huge range of possibilities. For example, the next stage of the exploration might involve shifting some or all of the one and two-bay frames off the building centreline – perhaps placing them on a curved line running between the ends of the building. While the structural performance is unaltered, such a move could create a particularly innovative and memorable building interior.

The following buildings illustrate the diverse range of architectural qualities that interior structure can help achieve. To begin, several spaces where structure itself creates a strong impression of being inhabited are examined. That is, occupants sense they inhabit structure that is located within a larger volume, rather than inhabiting the overall volume itself.

First, design studios in two schools of architecture are considered. In both, high spatial structural density and small-scale structural members

▲ **6.16** Portland Building, University of Portsmouth, England, Hampshire County Council Architects Department, 1996. The timber framework creates spatial zones within a studio.

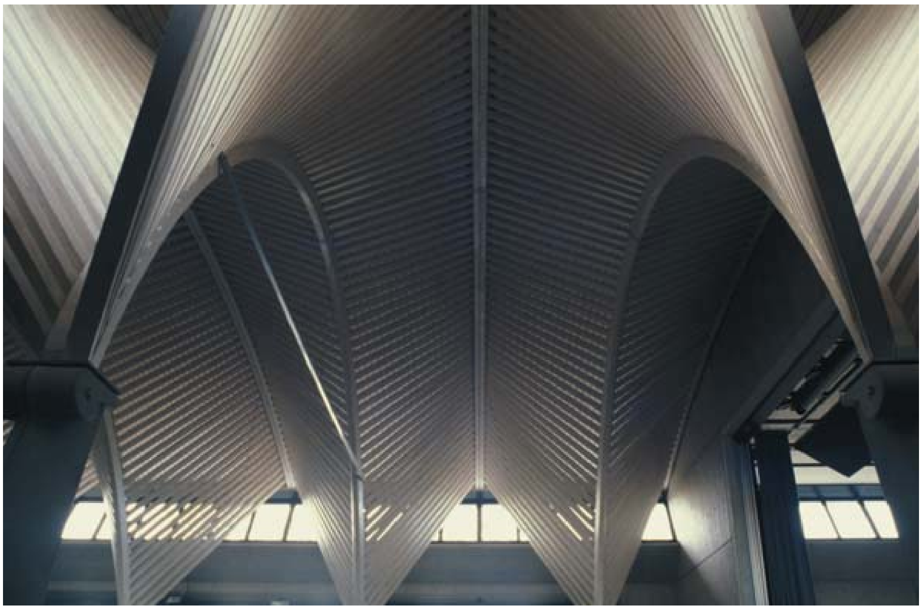
▲ **6.17** Lyons School of Architecture, Lyons, France, Jourda et Perraudin, 1988. Structure breaks up a large studio area.

create human-scale spaces. At the Portland Building, Portsmouth, an orthogonal post-and-beam framework supports the roof and creates a series of subdivided zones (Fig. 6.16). Spatial zoning is emphasized by how the architects have treated the framework as an insertion into the space and visually quite distinct from the roof. Although the roof slopes, the beams of the interior framework remain horizontal and thereby strengthen their definition of the smaller sub-spaces.

The double-height first-floor studios at the Lyons School of Architecture are broken up far more emphatically by the diagonal glue-laminated timber struts that prop the roof (Fig. 6.17). Mezzanine work spaces hang from the roof structure and create even more intimate working areas and spatial diversity within the large volumes. Students are never more than a metre or two away from a structural element, be it a strut or a mezzanine floor tension-tie. Although such a dense spatial structure limits how the studio space can be used, it creates a strong sense of fostering habitation and of framing activities occurring within the studios.

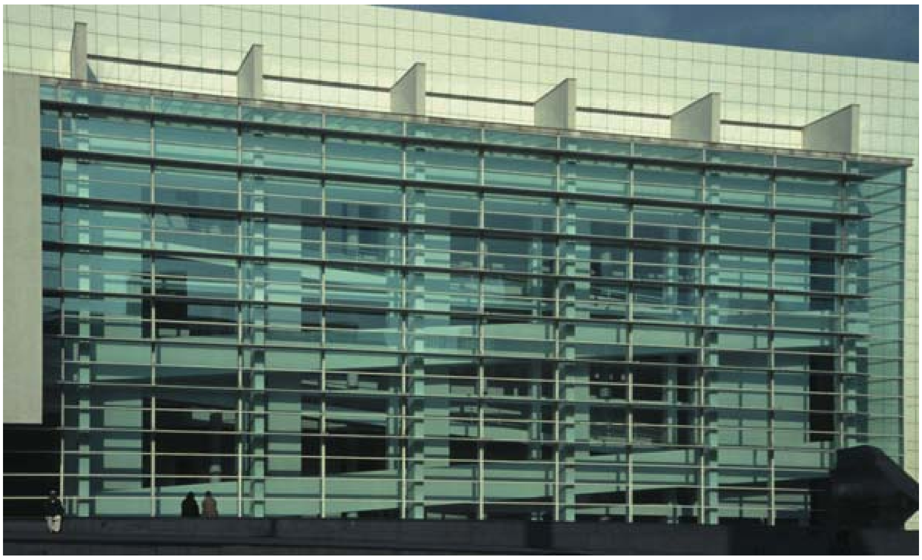
That same sense of the immediacy of structure is present in the Wohlen High School hall. In plan, regular column spacing articulates a central nave and side aisles. However, in section and when observed three-dimensionally, structure takes a far less conventional form. Free-standing roof support structure within the enclosing concrete walls dominates the interior (Figs 6.18 and 6.19). Gracefully curved pedestals support timber arches, and the radiating ribs create a delicate and intricate rhythmical structure. The frequency of ribs, their spatial orientation with respect to each other and the arches, and their white stain finish

▲ **6.18** Hall, Wohlen High School, Switzerland, Santiago Calatrava, 1988. A view towards the rear of the hall.



▲ **6.19** Looking across the hall.

make this structure so appealing. While timber details lack any elaboration, the precast concrete pedestals exhibit strong sculptural qualities. From a functional viewpoint the interior structure limits the hall's flexibility, but on the positive side it creates a wonderful and unique interior space.



▲ **6.20** Museum of Contemporary Art, Barcelona, Spain, Richard Meier Architects, 1995. Exterior glazed wall to the ramp-hall with the ramp structure behind.

Building users also intimately experience interior structure within the full-height atrium of the Museum of Contemporary Art, Barcelona. Continuing the theme of layering that is evident on the main façade, the atrium or ramp-hall contains three layers of vertical structure (Figs 6.20 and 6.21). Just inside the skin, a layer of thin rectangular columns support the roof and the three-storey glazed wall. Next, a free-standing colonnade interspersed with several non-structural vertical elements that also read as structure, carries ramps which cantilever from both sides of the columns. Beyond the ramp structure in a direction away from the glazed wall, the third layer of structure takes the form of another colonnade in front of the balconies and supporting beams emanating from the main galleries. The ramp-hall width is therefore defined by colonnades and inhabited by another carrying the ramps. Structure therefore plays a powerful role in spatial modulation. When ascending or descending the ramps, gallery visitors move past and close to these layers of vertical structure. Proximity to the structure and a rhythmical engagement with it all contribute to a sense of inhabiting it.

▲ **6.21** Ramp colonnade to the right and the innermost structural layer on the left.

Consideration of structure engendering a sense of being inhabited now leads to examples where structure plays more dynamic and dramatic roles, beginning with the Philharmonie auditorium, Berlin. The fragmentation of its surfaces used so effectively to break up undesirable sound reflections in the main auditorium, continues into the main foyer. Two pairs of raking columns support the underside of the sloping auditorium

▲ **6.22** Philharmonie, Berlin, Germany, Hans Scharoun, 1963. Some of the diverse structural elements in the foyer.

floor (Fig. 6.22). The foyer space is visually dynamic with many different structural elements – columns, piers, walls and bridges that support floors, circulation elements like staircases and walkways, and horizontal and sloping ceilings. The structure appears irregular, even spontaneous, and certainly not constrained to an orthogonal grid. The spatial profusion, density and diversity of the structural and circulation elements possess striking spatial qualities similar to those in Piranesi's *Carcere* etchings.

▲ **6.23** Stadttor Building, Dusseldorf, Germany, Petzinka Pink und Partner, 1998. An interior braced tower is visible through the glazing.

The Stadttor Building, Dusseldorf, provides another example of dramatic interior structure (Fig. 6.23). Two huge tubular-steel towers, located near diagonally opposing corners in plan, resist lateral loads. The architect has separated the gravity and lateral load resisting systems and chosen to express the latter. The concrete-filled structural steel members are massive by comparison to the light gravity-only columns whose small dimensions increase the building's transparency elsewhere in plan.

The braced towers are awe-inspiring in scale. The fact that they occupy voids and are themselves open, their height uninterrupted by floor slabs, means their entire size can be observed from many interior (and exterior) vantage points. Like giant masts, the structural towers are a defining characteristic of a building already endowed with other special features such as a vast atrium and extensive glazed façades. In terms of

▲ **6.24** A view up through a tower.

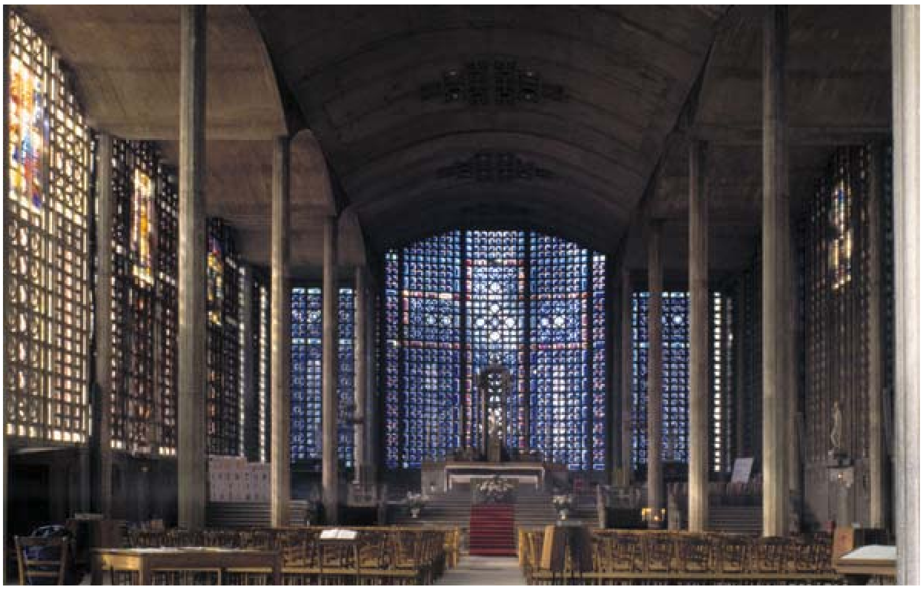
▲ **6.25** Fitzwilliam College Chapel, Cambridge, England, Richard MacCormac, 1991. Concrete frames demarcate a central area.

impact upon interior space, the towers with their diagonal braces are visually dynamic, but at the same time their scale is rather overwhelming. Patrons of a ground floor café situated near the base of a mast look up through the mast to the ceiling some 58 m above (Fig. 6.24). One can not imagine a less intimate and cosy interior space.

The next two examples of spatial structure lack any sense of the structural drama observed in the two previous examples, but illustrate how structure in a state-of-repose plays important spatial ordering roles.

Having discussed previously the rounded and protective exterior wall structure of Fitzwilliam College Chapel, Cambridge (see Fig. 4.35), the impact of a completely different structural system upon its interior space is examined. Three independent concrete frame structures stand within the confines of the chapel's walls. The central structure of four columns forms two frames in both orthogonal directions (Fig. 6.25). Together with the lowered concrete ceiling slab, the frames demarcate an area square in plan, centred between the walls. Two identical one-way frames flank the sides of this central structure. They are separated far enough from it to be read as independent frames, and with a large enough gap to house hot-water radiators. The four frames that align parallel to the major axis of the chapel therefore read as two sets of layered structure. The outer frames carry most of the weight of the timber roof that bears on inclined timber struts and cantilevers from them towards the curved walls (Fig. 6.26).

▲ **6.26** The timber roof is propped off an outer frame.



▲ **6.27** Nôtre Dame du Raincy, Paris, France, Auguste Perret, 1923. Church interior with its four rows of columns.

The interior frames set up a spatial hierarchy. Essentially they denote the importance of the liturgical activities by 'enclosing' the space occupied by the altar and sanctuary. The choice of white polished precast concrete for the frames further reinforces the importance of this space. Stairs and side seating occupy left-over spaces to each side of the frames. The space to the rear of the central frames accommodates most of the congregation, the organ and an additional staircase.

The second example, La Nôtre Dame du Raincy, Paris, also exemplifies structure ordering space (Fig. 6.27). Considered by some to be the world's first masterpiece of reinforced concrete architecture, its plan is typical of the neo-Gothic churches of that era. The church is five full bays long with an additional half-bay at each end. Four columns divide the width into two aisles and a central nave. The roof structure reinforces this tripartite order. A vaulted ceiling that relies on hidden transverse upstand-ribs for its support, runs the length of the nave while short aisle vaults are orientated transversely. Structural layout in plan appears to be based on a previous church design for the site, except that those original bay lengths were doubled by the architect to approximately 10 m.[12]

This modification immediately opened up the whole interior, reducing the distinction between nave and aisles and resulting in a lighter and more subtle ordering of space. Columns modulate both the whole volume as well as the side walls. Placing columns just inside the skin

▲ **6.28** Notre Dame de la Duchère, Lyons, France, F. Cottin, 1972. Posts supporting the roof are barely discernible.

▲ **6.29** The exterior wall is structurally separated from the roof by glazing.

rather than incorporating them into the wall maintains a clear distinction between the structure and the visually arresting pre-cast concrete and coloured glass building envelope. This relationship between columns and skin is also considered to increase the sense of spaciousness within the church.[13] The columns do not compete with the skin for attention but rather their slenderness and wide spacing enable them to blend in with it.

Before completing this discussion on how structure contributes to the spatial qualities of interior space a final example demonstrates an architectural concept that requires vertical structure to become almost invisible.

In the church of La Nôtre Dame de la Duchère, Lyons, its vertical structure fades into the background. Four slender cantilevered steel posts support the whole roof and also resist all the lateral loads acting on the building above eaves level. Lateral loads on the perimeter walls are resisted by regularly spaced columns incorporated into self-supporting walls that also cantilever from their foundations. Compared to the scale of the deep glue-laminated timber roof beams and the visual solidity of the ceiling, the posts are barely discernible (Fig. 6.28). Continuous strip windows that separate the perimeter columns and walls from the roof, reinforce the impression of the roof hovering (Fig. 6.29).

Expressive structure

The last section of this chapter focuses upon structure playing expressive roles. Examples of both surface and spatial interior structure instance structure expressing a wide range of ideas. The structures of

▲ **6.30** Museum of Gallo-Roman Civilization, Lyons France, Bernard Zehrfuss, 1975. A central row of continuous and sloping columns.

▲ **6.31** Concrete frames extend over the galleries and corridor. The sloping columns express the hill-side embedment of the building.

the first two buildings express resistance to external horizontal loads, while those that follow express aspects related to building usage and geometry.

Five floors of the Museum of Gallo-Roman Civilization, Lyons, are embedded in a hillside adjacent to an ancient amphitheatre. Apart from an uppermost entrance and reception level, the only other visible evidence of the museum are two small viewing galleries that project from the sloping face of the hill to overlook the nearby ruins, and vehicular access doors at the lowest level. Reinforced concrete frames rise up through the building and support suspended floor slabs (Fig. 6.30).

A strong structural presence permeates the underground volume. Large beams and columns project into galleries and modulate the spaces. Fortunately, their sensitive detailing avoids any undue structural severity. Curved junctions between beams and columns, and ceilings and walls, and tapered cross-sections of the beams soften the otherwise visual hardness of the concrete structure. Resistance to the lateral soil pressures acting on the rear wall is to some extent expressed by the general heaviness of the frame members, but is achieved primarily by the inclination of the outermost and central columns (Fig. 6.31). Their slope, which also reflects that of the vegetated hillside outside, expresses the structural buttressing often necessary to resist soil pressures.

The exposed structure at Westminster Station on the London Underground Jubilee Line also expresses the presence of external earth pressures. In the access-tunnels and around the train platforms, curved metal

▲ **6.32** Westminster Station, London, England, Michael Hopkins & Partners, 1999. Tunnel lining exposed at a platform.

▲ **6.33** Horizontal props between side walls.

tunnel liners, plates and bolts speak the unique language of underground construction (Fig. 6.32). However, the structure expresses the external pressures most clearly in the main hall (Fig. 6.33). Designed to be as open as possible, this huge 35 m high hall houses seventeen escalators and numerous floors that service the various lines that pass through

▲ **6.34** Props pass through a central column.

▲ **6.35** Kunsthal, Rotterdam, The Netherlands, Office for Metropolitan Architecture, 1992. Columns in the auditorium lean towards the dais.

the station. To add to its spatial complexity, eighteen 660 mm diameter horizontal steel struts pass across the hall and through a central row of vertical columns interspersed by cross-bracing. Welcome to another Piranesian space!

Both the surface and the spatial structure express the presence of external soil pressure. The hall side-walls are deeply patterned by a vertical grillage of projecting piers and horizontal beams. Interior surfaces that are recessed within these members present a rough shotcrete-like finish, often associated with soil retention. This quite massive surface wall structure, insufficient in itself to protect the hall walls from inwards collapse, is propped apart by circular solid cast-steel struts. The manner in which they are recessed into the wall structure at their ends expresses their role as compression struts. They read as thrusting into the wall and locally deforming it. At the centrally placed columns, projecting collars to the struts express the horizontal continuity required of the compression struts (Fig. 6.34).

Structure expresses different aspects of building use in the next four buildings. At the Kunsthal, Rotterdam, structure expresses a number of ideas. First, and at the most basic level, columns supporting the auditorium roof slope forward towards the dais (Fig. 6.35). By remaining orthogonal to the inclined plane of the auditorium floor the sloping columns focus attention to the front of the space – mimicking how people lean forward, eager to hear and see.

▲ **6.36** Unusually configured roof-plane bracing.

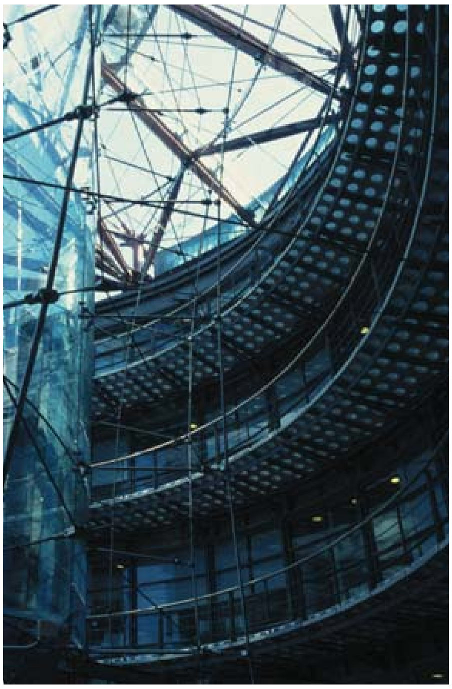
In other areas of the building, structure expresses qualities of the unexpected nature of the art on display. Within the Hall 2 gallery roof-plane, what appear to be irregular red-coloured bracing elements flash overhead as they pass between translucent truss cladding (Fig. 6.36). To the viewer these members form an unrecognizable pattern, raising the question as to whether or not they are structural.

Balmond, the structural engineer, explains:

> *In Hall 2 of Kunsthal a thin red line runs through the roof space. It is a small structural tube that follows, in plan, the path of an arch; and the curve intersects the roof beams to pick up lateral loads being delivered along those lines. Two pairs of ties reach out to prevent the arch from buckling in its plane of action. As the lines of the structural system of arch and tie become interrupted by the beams, it is not clear what the thin red line means. Is it structure? Is it pattern? Or, is it architectural device? The answer is; all three.*
>
> *Structure need not be comprehensible and explicit. There is no creed or absolute that dictates structure must be recognized as a basic functional skeleton or the manifestation of a high-tech machine. It can be subtle and more revealing. It is a richer experience to my mind if a puzzle is set or a layer of ambiguity lies over the reading of 'structure'.*[14]

Other unconventional interior structure in the Kunsthal also expresses the ambiguity mentioned above. Chapter 2 discusses how the two lines

▲ **6.37** An ambiguous relationship between a cantilevering slab and a tension-tie from the roof.



▲ **6.38** Channel 4 Headquarters, London, England, Richard Rogers Partnership, 1995. Atrium interior.

of columns 'slip' out-of-phase in Hall 1, and in a circulation space a thick slab appears to be propped near its end by a tension rod hung from a truss above (Fig. 6.37). But what is supporting what? The slab depth appears sufficient to cantilever without being propped. Perhaps the truss is being held down to counter wind uplift? The ambiguity is unexpected and unsettling.

Within the Channel 4 Headquarters entrance atrium, London, stainless steel cables visually express the dominant structural action, tension (Fig. 6.38). A tensile system, chosen for its transparency, supports curved and glazed atrium walls. Above the atrium roof, steel tension and compression members cantilever out from primary concrete structural elements to carry the weight of the entire glazed wall. Glass panels hang in tension from those above, with the uppermost panels transferring the accumulated weight to the main structure via shock-absorbing coiled springs. This load path is virtually invisible even when compared to the diminutive prestressed cable-net components that resist horizontal wind pressures on the glazed façade. The horizontal cables that follow the semi-circular plan shape of the glazed wall are stressed against vertical cables spanning between ground floor and the substantial roof cantilevers.[15] Slender horizontal steel tubes connect each glazed panel junction back to the taut cable-net. Precision-engineered connections signify state-of-the-art technology. The many cables, horizontal and vertical, as well as the tubes, result in visual as well as structural complexity.

As well as expressing structural actions, the structure also seems to express the atmosphere that pervades the building. The atrium space adjacent to the curved wall is one of the least visually restful spaces I have ever experienced. Most people who enter it play some part within the television industry. They pass through it quickly. The cables, all highly tensioned, trace out taut spatial patterns that are not immediately recognizable nor understood. This is a very visually busy structure, that as I read it, expresses the tension and stress often associated with performance – an architecture of tension, in more ways than one!

A more literal example of structure expressing an aspect of building use may be found at the glazed courtyard of the Oxford University Museum. Surrounded on three sides by heavy masonry wings of neo-Gothic construction, the cast-iron framework supporting the courtyard roof represents a remarkably light-weight structure (Fig. 6.39). The skeletal qualities of its load-bearing members are augmented by wrought-iron detailing that compliments the natural history exhibits on display. Haward acknowledges its expressive qualities when he reads the structure as a forest. He also sees it playing a didactic role, describing it as 'the

▲ **6.39** Courtyard, Oxford University Museum, England, Deane and Woodward, 1860. Courtyard interior.

▲ **6.40** Law Faculty Extension, Limoges, France, Massimiliano Fuksas, 1997. Walls of the interior lecture theatres protrude from the exterior wall.

central feature in the iconographic scheme for the Museum to be read as a "Book of Nature"'.[16]

Structure visually dominates the interior to such an extent that it may detract from the pre-historic animal skeletons on display. Both the metallic and the animal skeletons possess similar visual properties of complexity and delicacy. However, unlike the natural forms, the courtyard structure is elaborated by decorative detailing that serves to strengthen its relationship to natural history.

At the Law Faculty Extension, Limoges, structure both provides and expresses enclosure. Two bulging forms that protrude through the glazed skin hint at the rounded lecture theatres within (Fig. 6.40). The curved concrete ribs of the larger lower theatre support a smaller and lightweight version above.

Curved glue-laminated timber structure defines the interior volume of the smaller theatre (Fig. 6.41). Orthogonally orientated ribs accentuate its three-dimensional curvatures and visually emphasize the form of the womb-like interior. Primary and secondary ribs express enclosure as they wrap over and around the volume. Due to their significantly greater depth, the primary ribs play a stronger visual role. The horizontal confinement expressed by the continuous rings of secondary ribs is reinforced by the horizontality of the timber board wall-lining. Organic form, small scale, the sympathetic configuration of the structural elements,

▲ **6.41** Front of the smaller lecture theatre.

▲ **6.42** Library, Delft Technical University, The Netherlands, Mecanoo Architekten, 1997. Sloping columns in the study-hall.

and the materiality of timber all combine to realize a warm, intimate and embracing space.

In most buildings, orthogonally configured structural members both respond to and express the rectilinear structural systems and architectural forms they support. Even when forms take on more complex geometries, primary structure usually maintains a rigid adherence to orthogonality. However, there are exceptions. The previous chapter explained how structure at the Delft Technical University library subdivided space within the main hall (see Fig. 5.22). There, ground floor columns express the geometry of the element they support by matching the inclination of the cone surface above. The same approach is repeated in a computer-equipped study hall whose north-facing wall leans inward (Fig. 6.42). Column spacing along the wall is reduced to half of that elsewhere in the hall, and this doubles the columns' visual presence. The result is a dramatic leaning colonnade that supports, expresses and visually heightens the slope of the glazed skin.

Summary

Interior structure can transform otherwise nondescript interior spaces by contributing architectural qualities and character. This chapter presents three modes by which structure visually and conceptually enriches interior architecture – surface, spatial and expressive.

In the exploration of *surface* structure, the buildings discussed illustrate the architectural potential for enriching spaces using exposed structure located on interior surfaces. In several examples, quite elaborate structure creates attractive surface patterning. In others, exposure of structural elements that are normally concealed, coupled with a design approach characterized by simplicity and rigour, proves more than sufficient to transform spaces.

With respect to structure's *spatial* impacts, others have explained how structure generates a spatial field around it, affecting how a space is perceived and creating opportunities for 'place-making'. A simple study illustrates how, within the same volume, changes in structural layout can greatly affect how a space is read. Relatively small-scale structure that forms domestic-sized spatial units also affects our spatial experience. It instills an impression of being inhabited and of framing activities within it. Where larger in scale, interior structure offers many diverse spatial and visual experiences. At the extremes of structural scale, structure either all but disappears visually, or else its massiveness may be overwhelming. Structure also plays important roles ordering spaces, and in other cases, imposing a sense of spatial hierarchy.

The *expressive* potential of interior structure is boundless. The examples provided only begin to indicate the extent to which structure can express all manner of issues. Two structures illustrate expression of externally acting soil pressures. In another building, structure expresses concepts related to breaking conventions and 'the unexpected'. We also see structure mirroring the intensity of the emotional climate of one set of building occupants, and reassuring others in what could be termed 'a structural embrace'. Finally, interior structure can helpfully express and accentuate building geometries in such a way that leads to additional architectural enrichment.

REFERENCES AND NOTES

1 Cook, P. (1996). *Primer*. Academy Editions.
2 Cook (1996), p. 85.
3 Zerbst, R. (1991). *Antoni Gaudí*. Taschen, p. 115.
4 Ivy, R. A. (1992). *Fay Jones*. The American Institute of Architects Press, p. 35.
5 Brigatti, D. G. and Dahinden, J. (1997). *Spazi Evocanti il Mistero – la Chiesa S. Massimiliano Kolbe in Varese*. Grafiche Quirici, p. 114.
6 Pople, N. (2001). Caught in the web. *RIBA Journal*, Feb., pp. 37–44.
7 Ching, F. D. K. (1996). *Architecture: Form, Space & Order*, 2nd edn. John Wiley & Sons, p. 122.
8 Van Meiss, P. (1990). *Elements of Architecture: From Form to Place*. Van Nostrand Reinhold, p. 138.
9 Suckle, A. (1980). *By Their Own Design*. Whitney Library of Design, p. 14.
10 Abercrombie, S. (1983). Evaluation: Beaubourg already shows its years. *Architecture*, Sept., p. 70.
11 After Ogg, A. (1987). *Architecture in Steel: The Australian Context*. The Royal Australian Institute of Architects, p. 49.

12 Saint, A. (1991). Notre-Dame du Raincy. *The Architects' Journal*, 13 Feb., pp. 27–45.
13 See, for example, Frampton, K. (1995). *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture*. Massachusetts Institute of Technology, p. 132.
14 Balmond, C. (2002). *informal*. Prestel, p. 64.
15 For a more detailed description of the system's complexity and action, refer to Addis, W. (2001). *Creativity and Innovation: The Structural Engineer's Contribution to Design*. Architectural Press, pp. 113–15.
16 Haward, B. (1989). Oxford University Museum. *The Architects' Journal*, 27 Sept., pp. 40–63.