7 STRUCTURAL DETAILING

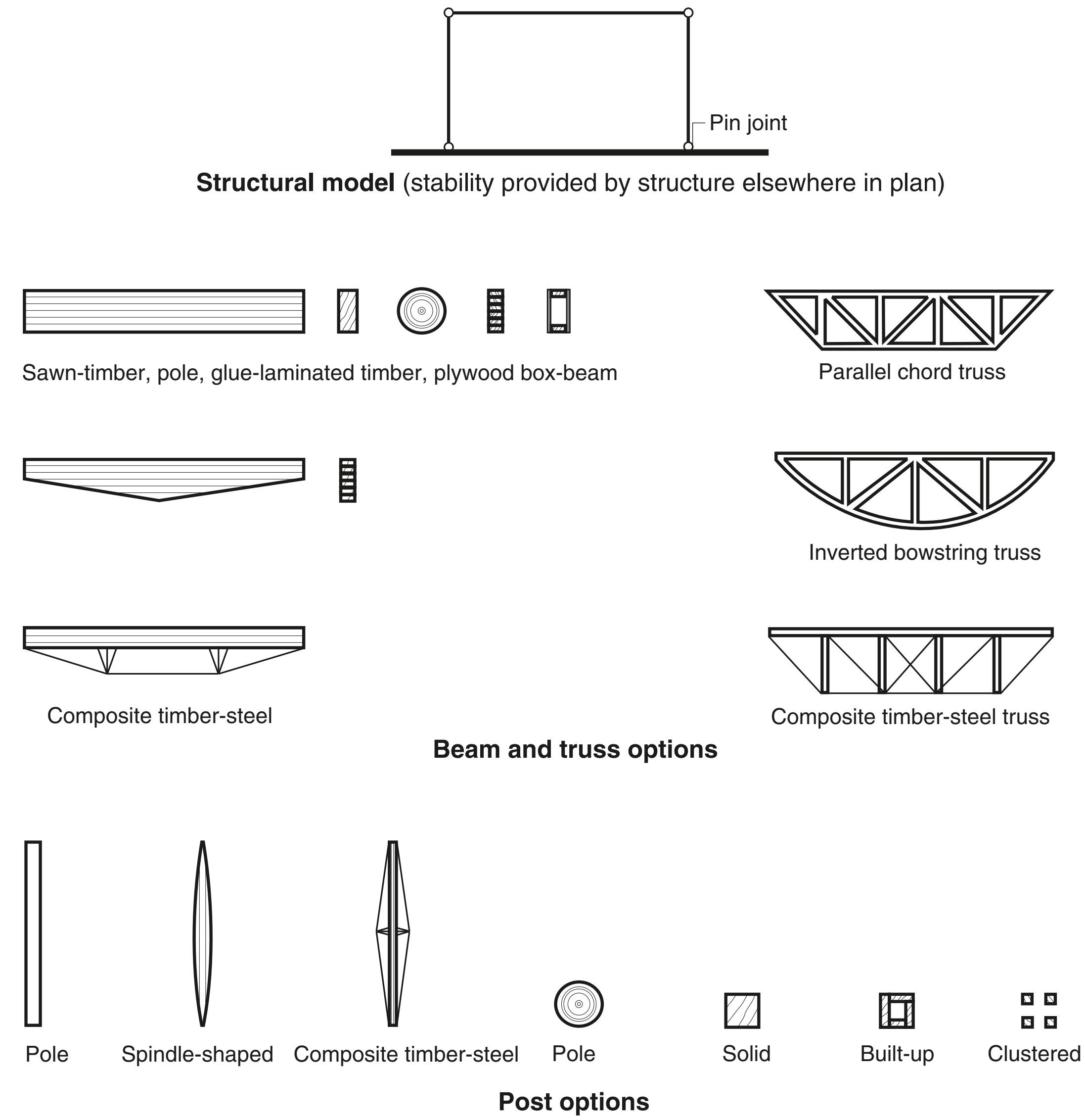
INTRODUCTION

Exposed structural detailing can contribute significantly to the architecture of a building. Detailing can transform ordinary or purely utilitarian structural members into objects of aesthetic delight, as well as communicating design ideas and concepts. This chapter begins by illustrating how architects express a wide diversity of design ideas through structural details. It then demonstrates the breadth of architectural qualities that detailing can contribute to designs, that in turn lead to aesthetically satisfying outcomes.

For the purposes of this discussion, structural detailing is understood as determining the form of and the shaping and finishing of structural members and their connections. Structural detailing, as a design process, comprises the design of the cross-section, elevational profile and the connections of a structural member in order to achieve the structural engineering requirements of stability, strength and stiffness. Detailing begins after the structural form for a given design is chosen. For example, if designers decide in principle to adopt an exposed timber post-and-beam system as shown in Fig. 7.1, they can select details from many possible combinations of differently detailed beams, columns, joints and finishes. A similar range of alternatives has been suggested for the detailing of structural steel members.[1]

The design concept should drive detailed design. Before attending to the specifics of structural details a designer should begin by revisiting his or her concept and interrogating it. How might it inform detailing decisions? Only then is it possible to achieve an architecture where all its structural members are integrated with all the other architectural elements and work together towards achieving the design concept. Such an outcome is improbable if a designer uncritically permits detailing choices to be constrained by typical or conventional practice. That will deny clients and building users opportunities for architectural enrichment. As Louis Khan writes:

> *A building is like a human. An architect has the opportunity of creating life. It's like a human body – like your hand. The way the knuckles and joints*



▲ **7.1** Alternative structural member options for timber post-and-beam construction.

come together make each hand interesting and beautiful. In a building these details should not be put into a mitten and hidden. You should make the most of them. Space is architectural when the evidence of how it is made is seen and comprehended.[2]

Where detailing is hidden from view, however, then any design considerations beyond structural performance, economy and buildability are wasted. A pragmatic approach to detailing is quite sufficient.

As well as reflecting or expressing the architectural design concept, as noted above, structural detailing must be structurally adequate and consistent with the structural engineering assumptions. For example, a connection assumed pinned in the structural analysis should be detailed as such. Therefore, at least in buildings large enough to require professional structural engineering expertise, successful structural resolution, including detailing, requires close collaboration between architects and structural engineers. Structural detailing should therefore satisfy both the architectural design concept and structural necessity.

Expressive and responsive detailing

Structural detailing expresses or responds to a wide variety of influences. In most cases, details are inspired by some aspect *within* the building being designed. Typical sources of inspiration include architectural form, function, materiality and construction, or structural actions. Examples of each are discussed in the following sections. Several buildings are then examined whose details reflect ideas or issues arising *outside* the building – perhaps an event, an aspect of technology, vernacular architecture, an aspect of culture or an historical period.

Architectural form

This detailing strategy adopts some feature of the architectural form to guide the development of structural details. If not laboured unduly, such an approach can bring a sense of harmony to a project, unifying otherwise possibly disparate elements. Where implemented successfully, the resulting details appear to have a sense of rightness or inevitability about them. As Architect Fay Jones, a widely acknowledged exponent of synthesizing the detail and the whole (architectural form) explains:

> *Organic architecture has a central generating idea; as in most organisms every part and every piece has a relationship. Each should benefit the other; there should be a family of form, and pattern. You should feel the relationship to the parts and the whole . . . The generating idea establishes the central characteristics, or the essence, or the nucleus, or the core; it's the seed idea that grows and generates the complete design, where it manifests itself from the large details down to the small subdivision of the details.*[3]

Two examples of structural details particularly well integrated with architectural form have already been mentioned briefly. In both, the detailing of the long-span vierendeel trusses at the Grande Arche (see Fig. 3.19), and the roof spine-beam at Saint Benedict Chapel (see Figs 6.4 and 6.5), detailing responds to form. Similarly well integrated relationships between structural detailing and architectural form are found at the Grand Louvre, Paris, and the Suhr office building.

In the underground foyer of the Louvre gallery, detailing of the coffered suspended ground floor slab reflects the precision and the geometrical

▲ 7.2 Grand Louvre, Paris, France, I. M. Pei, 1989. Louvre pyramid.

▲ 7.3 Coffered slab soffit.

▲ 7.4 Triangular recesses in the central column relate to the pyramid above.

▲ 7.5 Suhr office building, Switzerland, Santiago Calatrava, 1985. The building is circular in plan, with an attached service core behind.

purity of the famous glazed pyramid above (Figs 7.2 and 7.3). The truncated pyramidal geometry of the coffer voids within the slab unifies the different construction materials through common forms. Detailing of the central column also exhibits the same theme of geometrical purity (Fig. 7.4). Full-height triangular incisions into each side of an otherwise square column, form a complex cross-section. The square and triangular shapes integrate with those of the coffers in the immediate vicinity, and with the pyramid above.

Structural detailing of the Suhr office building takes its cue from an essentially rounded floor plan (Fig. 7.5). Geometrically complex paddle-like

▲ **7.6** Perimeter blade-like pier.

▲ **7.7** Rounded precast concrete stair stringer.

ground floor piers approximate circular cross-sections at their bases and widen smoothly to become thin blades at their tops (Fig. 7.6). The main stairway, tucked into a service core behind the primary circular form, also incorporates rounded details. The rounded top and bottom surfaces of the precast concrete stringer are also consistent with the architectural form (Fig. 7.7).

Building function

In the following two examples, a commercial building and an art gallery, structural detailing both expresses and contributes positively to aspects of their functions. In the first case the detailing is highly refined, while in the second, it has been deliberately designed to appear relatively crude. Structural detailing responds to and reinforces the distinctive purpose of each building.

The Tobias Grau office and warehouse facility, Rellingen, illustrates a most appropriate relationship between detailing and building function (see Fig. 3.30). The company designs and manufactures high quality light-fittings which have been incorporated extensively into its new facilities. In this setting, structural detailing maintains an equivalently high aesthetic standard. The structural details are more readily compar-able to those of furniture design than to typical building construction. The attractiveness of the main curved glue-laminated portal members is

▲ **7.8** Tobius Grau KG office, Rellingen, Germany, BRT Architekten, 1998. Structure in the office interior.

▲ **7.9** Fine diagonal bracing reads as 'stitching'.

surpassed by two lines of slightly inclined timber posts that delineate circulation from office area (Fig. 7.8). Spindle-shaped, the slender posts are capped top and bottom by conical steel shoes. The two bays of tension-only bracing are also far more elegant than usual. They avoid repeating the simple and conventional diagonal cross-braced solution where straight members connect to diagonally opposite joints. Structural refinement in the form of two additional rods that extend from the upper corners of the bays avoid the ubiquitous pair of diagonals. This structural complication yields a more visually interesting arch-like shape, increases the width available for circulation underneath the bracing and helps raise the level of structural sophistication to that of its surroundings. Even in the warehouse, fine rod cross-bracing has been so carefully designed and integrated with the portals, the wall-lining and the structurally essential horizontal members, that it reads more like sewing stitching than conventional bracing (Fig. 7.9).

Structural detailing also expresses aspects of building function at the Kunsthal, Rotterdam. When visitors approach the building at street level their aesthetic sensibilities are assaulted by two structural details. First, a large brightly painted unrefined I-beam projects crudely above the roof (Fig. 7.10). Secondly, adjacent to the main entry, three columns within close proximity to each other are detailed completely differently.

▲ **7.10** Kunsthal, Rotterdam, The Netherlands, Office for Metropolitan Architecture, 1992. Ungainly exterior beam.

▲ **7.11** Two of the three differently detailed columns.

The front two columns that form a steel rod cross-braced bay comprise a square concrete column and a castellated steel I-section (Fig. 7.11). The third column, behind, is a standard steel I-section. This deliberately inconsistent detailing expresses the nature of the unexpected and non-conformist art exhibits within. Structure, by flouting convention, expresses the ethos of this museum of modern art.

Structural engineer for the project, Cecil Balmond, explains why the columns 'disturb the air' and their personalities clash:

> *Imagine the same material and form for all the columns – there would be less impact. Imagine a regular spacing to the columns and the dynamic vanishes. Imagine further the different conflicts of plan resolved by some 'hidden' structural gymnastic, with one column coming through ultimately in a pretence of neatness – the reduction would be complete. There would be nothing left, no animation, no off-beat pulse. The juxtaposition brings in its own drama, and the mix urges entry, to by-pass the inconsistency for more settled regions within. These columns signal the experience of the building itself, with its schisms, its interior slips and jumps and separate materialities.*[4]

The expressive structural detailing at the Kunsthal recalls similar, albeit less provocative exterior detailing, at the BRIT School, London, whose imaginative detailing conveys the creativity and artistry the school seeks to engender (see Fig. 2.6).

▲ **7.12** United Airlines Terminal, Chicago, USA, Murphy/Jahn, 1987. The main concourse.

Materiality and construction

Some architecture is characterized by a strong expression of structural materiality and construction. Each structural material possesses features particular to its own materiality. For example, thinness of section, flanged cross-sectional shapes, potential for extreme slenderness in both compression and tension, and the ability to accommodate significant penetrations in members are characteristics unique to steel construction. Concrete, in a plastic or even completely fluid state while still fresh, can harden in moulds of almost any shape and display many different surface textures. Other signatures of concrete include negative details at construction joints and form-tie recesses. Timber materiality on the other hand is best expressed by its natural grain and colour, typical rectilinear cross-section shapes and connection details that respond to its relative softness and anisotropy. Certain structural configurations such as vertical and hierarchical layering of horizontal joists and beams, and relatively closely-spaced beams and posts are also trade-marks of timber construction.

This section, which illustrates structures whose detailing not only expresses building materiality and construction, but celebrates it, begins by considering a structural steel building whose materiality becomes apparent at first glance.

▲ **7.13** Beam–column junction.

The structure of the United Airlines Terminal concourse and departure lounges, Chicago, utilizes a limited vocabulary of two steel sections, the I-beam and the tube (Figs 7.12 and 7.13). Highly penetrated I-beams form the irregularly shaped beams of portal frames that articulate and modulate the concourses. Tubes function as purlins and also as clustered columns for each portal-frame leg. In several spaces the two sections combine to form a composite beam with a conventional top I-beam flange but a tubular lower flange.

The architect has mostly used off-the-shelf sections, yet through varied structural form and consistent and refined detailing has facilitated a sense of liveliness, lightness and materiality. The high quality detailing of the exposed structure is largely responsible for this exemplary architecture that could have otherwise been a featureless and elongated space. A reviewer observes:

> *Terminal 1 is not a project in which it is possible to hide a poor symbiosis of architecture and engineering disciplines; it is obvious that Jahn [the architect] and the structural engineers at Lev Zetlin Associates worked well together in an understanding of what the result should be. It has been noted that the structural expression so prevalent in the project – rounded forms, exposed ribs and structural members with punched webs – recalls the structural parts of aircraft; this layer of meaning, says Jahn, was unintentional . . . the assembly shows elegance in every detail. Steel connections and finishes could be the subject of a whole photographic essay in themselves. Joints, brackets, and end conditions have been taken past that point where they merely work, to become abstract sculpture.*[5]

Exposed structural detailing also plays a dominant architectural role at Hazel Wood School, Southampton. Throughout the building, circular timber columns support a glue-laminated lattice roof (Fig. 7.14). While exhibiting the layering so typical of timber construction, the roof structure takes that characteristic a step further by interlacing the beam chords and spacing them apart by timber blocks in much the same way as at Westminster Lodge, Dorset (see Fig. 6.8). The transverse beams spanning the school hall read as vierendeel trusses. Additional structural layering occurs locally above the columns where short glue-laminated beams cantilever either side of column centrelines to receive loads from the two-way lattice beams. These beam-column details recall the timber brackets of vernacular Japanese construction (Fig. 7.15).

Whereas timber construction dominates the interior architecture of Hazel Wood School, concrete structure plays a similarly strong aesthetic role at the Benetton Communication Research Centre, FABRICA, Treviso. Exposed concrete dominates the interior of this almost entirely underground project. In typical Ando fashion the detailing expresses the construction process (Fig. 7.16). Precisely spaced form-tie recesses,

▲ **7.14** Hazel Wood School, Southampton, England, Hampshire County Council Architects Department, 1990. The hall roof structure is typical of that for the whole school.

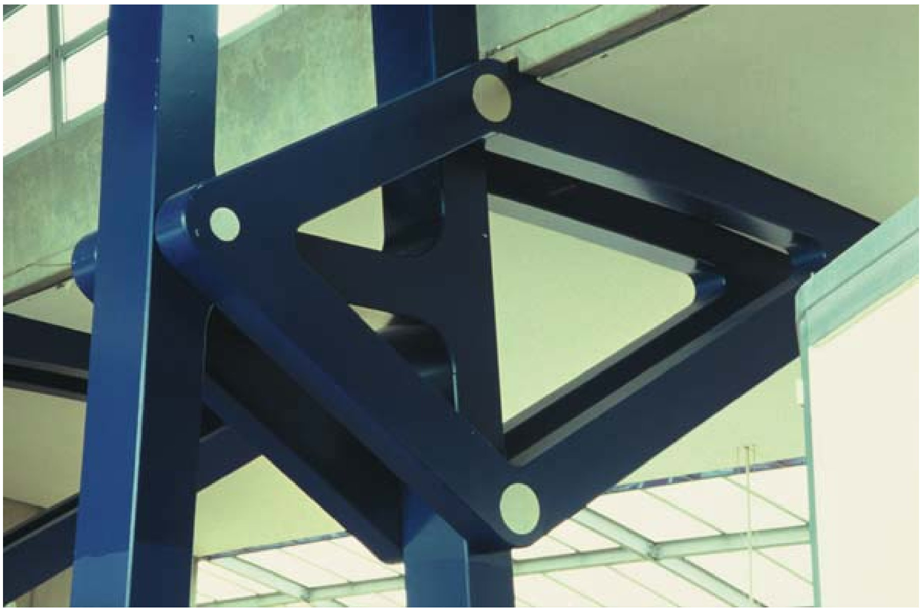
▲ **7.15** Short beams transfer loads from the lattice roof to a column.

▲ **7.16** FABRICA (Benetton Communication Research Centre), Treviso, Italy, Tadao Ando & Associates, 2000. Concrete construction and materiality are clearly expressed in the structural elements defining the sunken courtyard.

precision alignment of formwork joints and a high standard of concrete finish reflect the care devoted to structural detailing. Surface finishing is especially important here because of the plainness of all other column and wall details.

By restricting himself to circular and rectangular formwork Ando does not exploit the plasticity of concrete like Santiago Calatrava. Several of his works, including the cast-in-place concrete Stadelhofen Railway Station underground mall, Zürich (see Fig. 7.51) and Satolas Railway Station, Lyons (see Fig. 8.9), display comprehensively the extent to which

▲ 7.17 Ferry Terminal and office building, Hamburg, Germany, Alsop and Störmer, 1993. Partially exposed precast concrete A-frames.



▲ 7.18 Precast bracket and frame junction.

concrete's materiality can be expressed. These buildings are essays in the architectural exploitation and expression of cast-in-place concrete as a structural material.

The typical characteristics of precast concrete – thin and compact cross-sections, relatively complex forms and repetitive member layout – are exemplified in the Ferry Terminal and office building, Hamburg (Fig. 7.17). Thirty-three pairs of precast concrete A-frames define the 200 m long building. Generally placed just inside the exterior skin on each side of the building, each pair of frames supports simply-supported beams and suspended floor slabs that span between them.

Several frame bases are exposed within the ferry terminal waiting-room. They support precast concrete cantilever brackets, similarly detailed as the main frames, to extend the terminal area beyond the main building line (Fig. 7.18). Given their skeletal form, blue painted finish and smallness of cross-section, the brackets could actually be mistaken for steel construction! The architect clearly articulates the pin connections between the A-frames and their brackets, and therefore emphasizes the site-jointed nature of the precast components. Both in their forms and connections, the brackets and frames are consistent with and expressive of the materiality of precast concrete.

The final two examples where structural materiality and construction are expressed clearly begin with the Guggenheim Museum, Bilbao. Just enough structure is exposed to explain the building's construction

▲ **7.19** Guggenheim Museum, Bilbao, Spain, Frank O. Gehry & Associates, 1997. View of the museum from the Puente de La Salve bridge.

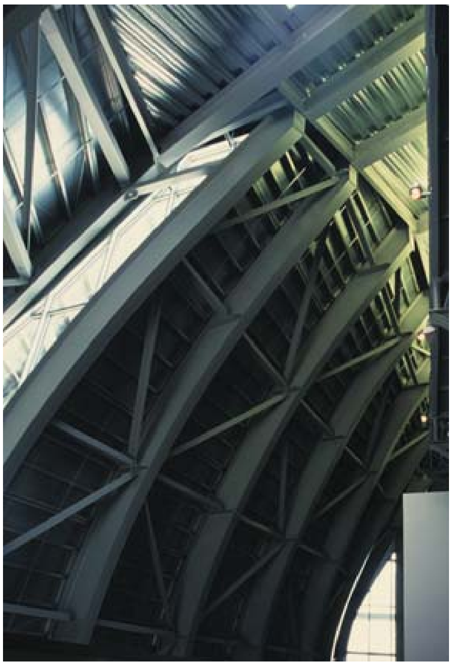
(Fig. 7.19). Although the structure of this remarkable building lies mainly hidden within its billowing and twisted sculptural forms, in several locations its skeletal steel structure is exposed. The most accessible and informative area of this exposure occurs at the tower (Fig. 7.20). In conjunction with the long gallery, the tower 'holds' the Puente de La Salve bridge to the main body of the museum. The exposed tower structure, visible from the bridge, explains how other building exterior surfaces are structured. Rather unexpectedly, a conceptually simple triangulated steel framework supports the geometrically complex skins. Compared to the audacious titanium clad three-dimensional curved surfaces, the adjacent structural details of nuts and bolts and standard steel sections appear quite crude. Their ordinariness disguises the extent of the underlying structural analytical and design sophistication.

▲ **7.20** The tower structure.

On a far smaller scale, and more overtly than at Bilbao, Frank Gehry expresses the nuts and bolts of structure *inside* the Fisher Center, Annadale-on-Hudson, New York. Curved steel ribs and bent horizontal girts are the means of achieving the dramatic sculptural walls that form a protective skin around the main theatre (Figs 7.21 and 7.22). Steel I-sections, their flanges welded to curved web plates, rise from their foundations and span a four storey volume to gain support from the concrete walls that enclose the theatre. Braced within their planes, the entire construction of these ribbed walls – the inside surfaces of the stainless steel cladding sheets, the girts, ties, braces, cleats and even the

▲ **7.21** Fisher Center, Bard College, Annadale-on-Hudson, New York, USA, Frank O. Gehry & Associates, 2002. Side elevation with the main entry canopy to the right.

heads of the self-tapping screws that connect the different components together, are exposed in a rare architectural move.



▲ **7.22** Exposed construction of an exterior wall that curves towards the theatre roof.

At the Carpentry Training School, Murau, exposure of structural detailing extends beyond 'informing' to 'educating' (Fig. 7.23). The timber roof structure can be envisaged playing an important pedagogical role in the life of the school – like the sprung-tensioned system of the Parisian civil engineering school (see Fig. 3.51). Given that the structural members of the workshop-spanning trusses are ordinary straight lengths of glue-laminated timber, their visually prominent connections awaken interest in structural detailing. The deep roof structure relies upon steel plates to join its timber members together. The plates, inserted into and fixed to the timber members by pressed-in steel dowels are then bolted together (Fig. 7.24).

Another more elegant detail, but less visible due to its height above ground, occurs at the level of clerestory glazing (Fig. 7.25). Stainless steel plates are bolted to timber studs to extend their height to eaves level. This unusual detail enables the combined timber–steel studs to span vertically between the floor slab and the roof diaphragm to which they transfer wind face-loads. Importantly, the detail expresses the fact that the exterior walls do not provide vertical support to the roof – the thin vertical plates are weak in compression. Under lateral loads, however, they bear horizontally against a steel rod that passes through their

▲ **7.23** Carpentry Training School, Murau, Austria, E. Giselbrecht, 1992. Rear elevation.

▲ **7.24** Web members connect to a truss bottom-chord.

▲ **7.25** Face-loads only are transferred through the plate-rod connection.

vertical slots. This detail simultaneously allows horizontal load transfer and unrestrained vertical movement between the plates and the roof structure.

Structural actions

Detailing that expresses structural actions within members and connections also provides opportunities for architectural enrichment. According to Collins, Soufflot, the eighteenth-century Rationalist architect who reacted against the ornamental embellishment of structural details, advocated 'simply limiting aesthetic effects to those which logically followed from the nature of the structural component, and designing those components in accordance with rational criteria'.[6] But the pendulum has swung since the 1700s. Now, architects such as Louis Kahn react against bland concrete and timber members muted by their rectilinearity in both cross-section and longitudinal elevation, and 'off-the-shelf' steel sections that satisfy nothing other than the outcome of engineering calculations. Referring to the pervasive use of steel I-beams, Khan criticized structural engineers who used excessive factors-of-safety in conjunction with steel beam standardization. In his view, this led to overly large member sizes 'and further limited the field of engineering expression stifling the creation of the more graceful forms which the stress diagrams indicated.'[7]

In the following examples where detailing expresses structural actions, including bending moment diagrams, two distinct types of expression may be found. In the first, detailing expresses the variation of structural actions, and nothing else. In the second type, to use Anderson's words, 'The functionally adequate form must be adapted so as to give expression to its function. The sense of bearing provided by the entasis of

▲ 7.26 Jussieu University, Paris, France, Edouart Albert, 1965. Beam geometry expresses the bending moment diagram.

Greek columns became the touchstone of this concept . . .'[8] In other words, designers elaborate structural details in order to clarify the expression of structural action. First, then, unelaborated structural detailing.

The exposed first floor beams at Jussieu University, Paris, express their internal structural actions. Steel box-beams, curved both in elevation and plan, express the relative intensity of their bending moments (Fig. 7.26). The beams are simply supported and their elevational profiles take on the parabolic forms of their bending moment diagrams. One notes in passing that the architect has privileged the articulation of bending stress rather than shear stress. Shear stress, which usually increases linearly from a value of zero at a mid-span to reach its maximum value at the ends of a span, is rarely expressed. The suspended floor trusses at Centre Pompidou, Paris, are an exception (see Fig. 7.53). Their diagonal web members increase in diameter as they approach the truss supports in response to the increasing value of shear force.

By varying the beam flange-width in plan at the university, the beams narrow at their ends to match the diameter of the tubular-steel columns into which they frame. Such a high degree of column slenderness, given that the columns support five floors, indicates their inability to resist lateral loads and the necessity for the concrete structural cores elsewhere in the building plan to provide overall stability. The level of transparency provided by these small diameter columns is especially appreciated

▲ **7.27** Stadelhofen Railway Station, Zürich, Switzerland, Santiago Calatrava, 1990. Escalator entrance structure.

▲ **7.28** Upper cantilever-to-torsion-beam connection, with smaller canopy cantilevers in the background.

given the 'sagging' beam profiles. Zannos suggests that designers should avoid this type of structural detailing:

> *If it is indeed true that we dislike forms that appear weak because their shape is deformed or seems to have been deformed by loading, it is quite natural that we prefer forms that are in contrast to that shape. We may thus propose the following law of aesthetics: a form . . . agrees with our aesthetic intuition – and, hence, satisfies us aesthetically – if its shape contrasts the shape that would have resulted if the form had been deformed by loading.*[9]

In this building, rather than the sagging beam soffits creating the sense of oppression that might be experienced in a more enclosed space, they lead the eye away from any potential visual heaviness towards the light and the open space on either side of the building.

The Stadelhofen Railway Station, Zürich, comprises a number of steel and concrete structures all of which to some degree illustrate detailing that expresses structural actions. For example, consider an escalator entrance structure (Fig. 7.27). The upper cantilever springs from a short pier bolted to a concrete base whose top surface slopes parallel with the cantilever. Immediately, by inclining its base Calatrava introduces a sense of dynamism to the structural form.

Like all other cantilever beams in the station, the cantilever tapers to a point, approximating the shape of its bending moment diagram. Near its end it supports an unusually configured and orientated two-pinned frame whose member profiles also match their bending moment diagrams. The form of this hanging lower structure recalls that of a swimmer diving. Under each of the two canopies of the escalator entrance, smaller beams cantilever from tubular torsion-resistant beams. The circular bolted plates express the transfer of torsion into the main members (Fig. 7.28). Here, detailing not only expresses structural actions

▲ 7.29 Stratford Regional Station, London, England, Wilkinson Eyre, 1999. Curved frames spring from cast-steel bases.

▲ 7.30 Lyons School of Architecture, France, Jourda et Perraudin, 1988. A cast-steel shoe expresses the compression load-path.

but its anthropomorphic forms create an aesthetic of movement and lightness.

At another railway station, the Stratford Regional Station, London, structural actions similarly inspire expressive detailing (Fig. 7.29). Although the focus here is upon just one detail, the base-connection of the portal frames, other details, such as how the primary curved frames taper to points where they are propped, equally express structural action. Each frame base-connection joins the frame rigidly to a concrete substructure. This base rigidity helps the frame resist gravity and lateral loads, and minimizes its depth.

High-strength bars tension the base-plates down to the concrete via cast-steel bases. Rather than adopt usual construction practice whereby a column base-plate connects directly to a concrete foundation by vertical bolts whose shafts are concealed, this detailing expresses how the base-plate is clamped down. Not only are the bolt shafts visible, but their inclination aligns them parallel to the lines of stress within the frame member. The shaping and roundness of the base exemplifies the 'adapting' of form, spoken of by Anderson previously. The base expresses and elaborates how tensions from the embedded bars compress the base-plate against the concrete, and how this compression stress that acts upon the base is dispersed uniformly at the steel-base to concrete interface.

Connections of timber members at the Lyons School of Architecture, Lyons, present a more overt example of elaborating structural details for the sake of improved expression (see Fig. 6.17). Delicate cast-steel shoes provide the transition detail at both ends of the inclined struts and vertical columns (Fig. 7.30). The elaboration of these details takes the form of four ribs that fan out from the steel-pin housing, and spread over the member depth, expressing the flow of compression force just as effectively as do the attached shafts of Gothic piers. The ribs illustrate how force is transferred from a relatively large and soft timber cross-section and channelled into a far smaller and harder steel pin.

The detail is adapted for beam-column connections, although the expression of (shear) force flowing from beam to column through the castings is less obvious (Fig. 7.31). What *is* clear however is an expression of clamping action – of the timber beam being clamped between castings that are fixed to the timber by screws top and bottom. Rather than expressing load paths, the clamping nature of the connection mechanism is communicated visually. This detail is a reminder of Chernikhov's seven constructivist joints, each of which expresses a different nature of connection.[10] Before leaving this junction, note that its unusual form allows a down-pipe to pass through it, just millimetres from the end of the beam. This is a simple example of how the necessity for structure and services integration frequently gives rise to inventive and expressive structural forms and details.[11]

The final example where detailing is inspired by some feature inherent in the building, expresses another form of connectivity – clasping. An oriel on the main façade of Palau Güell, Barcelona, projects over the street and is supported underneath by short cantilevers (Fig. 7.32). Their rounded profiles are mirrored by a row of similar cantilevers above the roof. Both sets of cantilevers appear to be doing more than just supporting gravity loads. Their tips wrap around and against the horizontal slabs as if to prevent them from sliding towards the street. Taking the form of bent fingers holding a cell-phone in the hand, they

▲ **7.31** A beam-column connection where a horizontal gap between the castings allows for a down-pipe to pass through the detail where required.

▲ **7.32** Palau Güell, Barcelona, Spain, Antonio Gaudí, 1880. Cantilevering brackets clasp the oriel floor.

read as clasps – like those restraining jewels in their settings, holding the oriel against the main building.

Other sources of inspiration

To conclude this study of expressive and responsive detailing, three examples are noted where structural details are inspired by sources from outside the building or its programme. First, the eclectic structural detailing of the Glasgow School of Art roof structures, where above the main stair and surrounding exhibition space, decorative timber trusses evoke images of medieval construction (Fig. 7.33). In another space, a roof bracket detail indicates a Japanese influence (Fig. 7.34).

At the post-modern Staatsgalerie, Stuttgart, structural details also draw upon a diverse range of external sources (Figs 7.35 and 7.36). The

▲ **7.33** Glasgow School of Art, Scotland, Charles Rennie Mackintosh, 1899. Truss forms inspired by medieval construction.

▲ **7.34** An elaborate roof-beam bracket.

▲ **7.35** Staatsgalerie, Stuttgart, Germany, James Stirling, Wilford & Associates, 1984. A classically detailed structure frames an entrance.

▲ **7.36** Mushroom reinforced concrete columns in a gallery.

columns and lintel that frame an exterior entrance, clearly express their classical origins. Inside the building, concrete mushroom columns are exposed in several spaces. They evoke images of the flat-slab columns that were introduced in the early 1900s, and in particular, those columns that support the roof of Frank Lloyd Wright's 1930s Johnson Wax administration building, Racine, Wisconsin.

Rather than drawing upon historical sources to inform the detailing of the Beehive, Culver City, California, the architect explores ideas of 'balanced unbalance'.[12] At ground floor the structural form is as unusual as the structural detailing above. Four square hollow-section posts that appear to be haphazardly orientated in plan and section lean outwards and are wrapped around horizontally by regularly spaced steel pipes that generate the curved form akin to an inverted beehive (Fig. 7.37). At first floor one encounters most unconventional structural detailing. The two rear posts kink as in a knee-joint, but the detailing suggests that the structure has snapped in bending. The rotation at each joint is expressed graphically by a triangular 'crack' or gap between the upper and lower sections of the posts (Fig. 7.38). Notions of instability, fragility and damage are conjured up in one's mind. Only upon closer inspection one sees how welded steel plates within the hollow sections provide enough strength for structural safety.

▲ **7.37** The Beehive, Culver City, USA, Eric Owen Moss Architects, 2001. The exterior with the main entrance to the left.

▲ **7.38** A 'broken' post at first-floor level.

Aesthetic qualities of detailing

Introduction

This section explores and illustrates the enormous diversity of the aesthetic qualities of structural detailing. Pairs of contrasting qualities are categorized into four broad groupings. The process of categorization is imprecise since some details can be discussed in the context of another grouping. But the purpose is not to pigeon-hole a detail aesthetically, but rather to illustrate the amazing variety of different structural languages and approaches to structural detailing. Each detail invites its own architectural reading and influences how building users perceive and experience the architecture of which it is part.

Refined to utilitarian

Although one might expect refined structural detailing in all works of architecture, this certainly is not the case. Sometimes the budget or time constraints frustrate opportunities for refinement. Perhaps to ensure consistency with an architectural concept that for example requires a raw industrial aesthetic, refinement is avoided deliberately.

Refined structural details are frequently described by such terms as pure and elegant. Any extraneous material and componentry has been edited away. One is left with the impression that the detail cannot be improved upon. It has undergone an extensive process of reworking that has left the designer satisfied with the outcome – the technical and aesthetic requirements resolved in a synthesis of structural necessity and artistic sensibility.

Beginning with two examples of refined detailing, readers will recall that the expression of architectural quality on the exterior of Bracken House, London, has already been discussed and some of its exposed details noted (see Figs 4.40 and 4.41). The building's exterior provides other examples of refined detailing, such as on the main entrance truss that supports a translucent canopy (Figs 7.39 and 7.40). Metal bosses articulate the joints between the bottom-chord members and the others that are inclined. The spoke-like diagonals, ribbed and tapered to match the structural dimensions at each end, possess the same visual qualities as elegant mechanical or aeronautical engineering components.

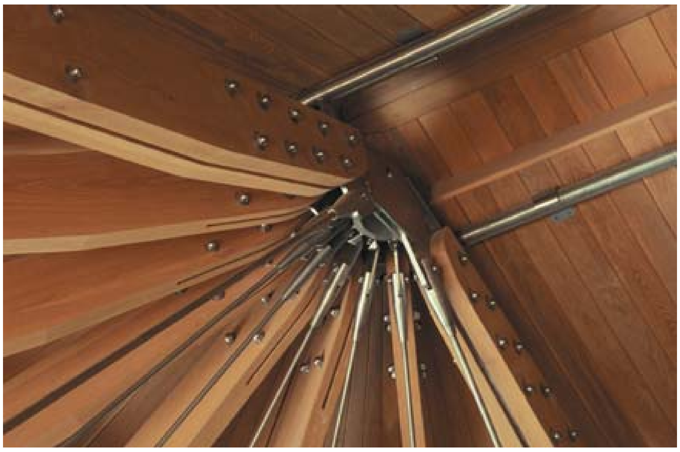
A similar high degree of structural detailing refinement is evident at Queen's Building, Cambridge (Fig. 7.41). In describing it, a reviewer observes: 'One would say that the building was a montage of Hopkins motifs, were it not such a unified, monolithic form – more like a beautifully crafted piece of furniture than a building.'[13] The composite timber and stainless-steel theatre roof trusses incorporate refined structural

▲ 7.39 Bracken House, London, England, Michael Hopkins and Partners, 1991. Main entrance canopy.

▲ 7.40 Refined truss members.

▲ 7.41 Queen's Building, Cambridge, England, Michael Hopkins and Partners, 1995. Main façade.

details (Fig. 7.42). Precisely located bolts pass through stainless-steel plates inserted between timber members. Rods elegantly connect to and fan out from a plate at a truss apex. The building exterior also features notable exposed structural detailing. Small stainless-steel ring-nodes denote the anchorages of an innovative post-tensioning system



▲ **7.42** Refined roof truss detailing.

▲ **7.43** A post-tensioning node detail.

▲ **7.44** School of Architecture, Marne-la-Vallée, Paris, France, Bernard Tschumi, 1999. Looking towards the main entrance.

▲ **7.45** Unrefined steel beams pass over a work-space atop the lecture block inserted into the atrium.

that reinforces the solid limestone masonry piers (Fig. 7.43). Specially selected aggregates for the concrete blocks housing the nodes match the colour of the surrounding stone blocks.

The School of Architecture, Marne-la-Vallée, Paris, illustrates less refined detailing (Figs 7.44 and 7.45). An industrial quality pervades the all-concrete-and-steel exposed structure. Consider the four steel beams that span an internal atrium, partially occupied by a box-like lecture theatre. Their unrefined cross-sections and longitudinal profiles raise questions such as why their shapes have not been better integrated with the saw-tooth roof form? However, this beam detailing *is* consistent with the basic quality of exposed steelwork elsewhere whose galvanized surfaces are left unpainted. The standard of detailing

▲ 7.46 Attic conversion, Vienna, Austria, Coop Himmelb(l)au, 1988. The attic roof over-sails the existing building.

▲ 7.47 Irregularity of the form is reflected in the detailing.

is totally compatible with the architect's concept: 'It's never a closed system . . . You never contain it. You always leave gaps, interstices. It's never about synthesis. It's always about certain fractures. So the fractures are generally all intentional. It's not like Norman Foster who will always try to close the system. I always try to leave it open.'[14]

In contrast to the refined structural detailing of Bracken House and Queen's Building and the more basic detailing of the School of Architecture, raw and irregular details characterize the Attic conversion, Vienna (Figs 7.46 and 7.47). Such a deliberate lack of refinement again seems quite appropriate within a chaotic structural assemblage described variously as 'an eagle', 'a crazy composition', 'a snapshot of a disastrous collision' and 'a constructional thunderstorm'! Details therefore mirror the general absence of structural rationality. Their random and fractured qualities verge on the crude.

Simple to complex

This grouping of aesthetic qualities is not intended to imply an absence of refinement, and in fact, both the following examples illustrate refinement in different ways. At the Millennium Seed Bank, Sussex, details have been pared down to the bare minimum (Figs 7.48 and 7.49). A 'less is more' approach complements the simple barrel-vaulted and frame forms. This simple and restful architecture achieves the architect's design concept to 'evoke a sense of spirituality and create a space for private reflection where both adult and child should leave feeling enriched.'[15]

Conversely, the Louvre Pyramid, Paris (see Fig. 7.2) illustrates complex detailing. Although a simple architectural form, an aspiration for

▲ **7.48** Millennium Seed Bank, Wakehurst Place, Sussex, England, Stanton Williams, 2000. Barrel-vaulted roof forms.

▲ **7.49** Detailing matches the simple structural forms.

▲ **7.50** Grand Louvre, Paris, France, I. M. Pei, 1989. Visually confusing structure.

transparency has led to structural complexity. Rather than frame the pyramid conventionally with solid sloping rafters spanning between the base and the four ridges of the pyramid, the architect opted for a diagonally orientated system – a two-way grillage of stressed cable-beams. While small diameter stainless-steel members offer a high degree of transparency, from many viewing angles the profusion of rods and connections is visually confusing (Fig. 7.50). Visual complexity arises primarily due to the large number of individual members, even though each is small.

▲ **7.51** Stadelhofen Railway Station, Zürich, Switzerland, Santiago Calatrava, 1990. Cambering the beams and the 'sloping columns' visually lighten the shopping mall.

▲ **7.52** Pier detailing.

Lightness to heaviness

Designers often seek to maximize ingress of natural light and achieve a high degree of transparency in external walls as discussed more extensively in Chapter 8. They usually adopt a strategy entailing many slender, rather than fewer larger members. As noted at the Louvre pyramid, while structure might exhibit acceptable qualities of lightness and transparency, from some viewpoints its appearance is less successful. It is important to remember that people mostly view and experience structure from positions other than those used to generate plans, sections and elevations.

Sensitivity to human proximity also motivates a lightness of touch in detailing. Visual harshness of members and perceptions of size can be relieved by introducing curved surfaces, as in the subterranean Museum of Gallo-Roman Civilization, Lyons (see Figs 6.30 and 6.31). Chamfering the lower third of the deep beams and the smooth curved transitions between the columns and beams softens their visual impact and renders the structure less formidable. Rounded surfaces incorporated into the precast concrete floor units also 'soften' the concrete soffits and achieve an attractive textured ceiling. Concrete surfaces can also be 'softened' in a tactile and visual sense by sandblasting, as in the Cambridge Law Faculty Building, Cambridge (see Fig. 7.61), or by light bush-hammering.

The Stadelhofen Railway Station underground mall, Zürich, also exemplifies detailing that visually lightens otherwise large concrete members (Figs 7.51 and 7.52). Pier detailing incorporates two setbacks in plan

▲ **7.53** Centre Pompidou, Paris, France, Piano and Rogers, 1977. Double-chords reduce the visual mass of the truss.

that reduces its visual mass and scale, rendering the space more amenable to human habitation. The thinnest portion of a pier cross-section when traced from its base up to the beam and down to the base of the opposite pier reads as a portal frame. The next thicker area appears to be supporting and connected to the keel-like ceiling shape, and the thickest remaining section is seen as part of the walls above the shop frontages. Structural details like these downsize one's perception of structure towards human-scale and create friendlier, more humane environments.

▲ **7.54** Institut du Monde Arabe, Paris, France, Jean Nouvel, 1987. Light vierendeel trusses support the end wall.

Use of multiple members is another strategy to prevent people from feeling overwhelmed by otherwise large structural elements. The double-chords of the Pompidou Centre trusses, Paris, have their visual mass reduced to a minimum (Fig. 7.53 and see Fig. 4.18), and the clustered columns of the United Airlines Terminal have a similar effect (see Fig. 7.13). Multiplicity of structural members may bring additional aesthetic benefits as well, such as introducing a sense of rhythm to an elevation or a space.

Returning to lightness of detailing for transparency, L'Institut du Monde Arabe, Paris, illustrates in at least two areas a successful detailing strategy utilizing composite rather than solid members. Open vierendeel box-trusses span the width of the narrow exterior wall of the main façade (Fig. 7.54). Positioned in front of the cladding, they offer support to it at each floor level. With their outer chords curved in plan, they

▲ **7.55** Internal horizontal trusses in the library.

contribute a diaphanous softness to the façade. Other internal box trusses support the skin in double-height spaces such as the library. But these are detailed completely differently. Diagonal web members, together with four parallel tubular chords, achieve new qualities of intricacy and ornateness (Fig. 7.55). Their transparency and visual complexity compliment similar qualities present in the glazed and mechanically shuttered curtain-walls. It is worth reflecting on how greatly the aesthetic qualities of the space would change if the existing trusses were replaced by solid box or tubular-beams.

Another example of structural detailing for lightness can be observed in Charles de Gaulle Airport, Terminal 2F, Paris. Whereas in the first visit to the building it was noted how the massive exterior structure signalled entry (see Fig. 4.30), now the structural lightness inside the terminal is experienced. A 200 m long 'peninsula' that houses departure lounges and aircraft walkways juts out from the air-side of the main terminal building. A series of transverse portal frames whose detailing is so 'light' that the whole structure almost reads as a space frame, supports its roof (Figs 7.56 and 7.57). Structural detailing is not locked into an orthogonal grid but responds to the roof form that appears like an upturned boat hull. The truss nodes map the gently curving roof contours, and via innovative light-weight tension-spokes, the trusses wrap around and under the floor slab. The structure delivers a light-filled space while displaying a remarkable degree of lightness. Compared to the heaviness of the terminal land-side concrete wall and ceiling surfaces, this air-side structure looks as if it could take off!

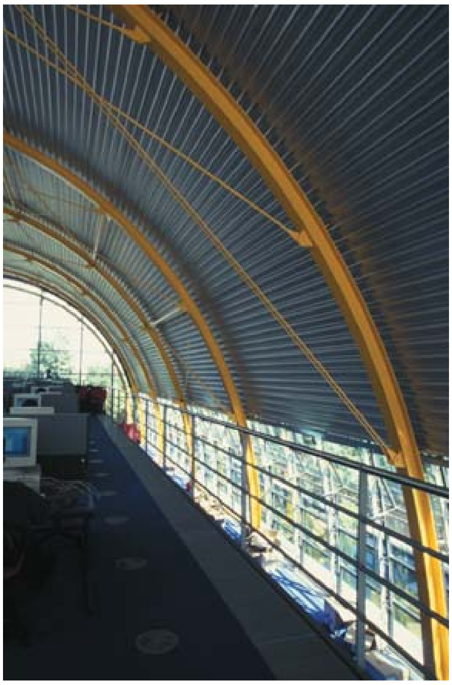
▲ **7.56** Charles de Gaulle Airport: Terminal 2F, Paris, France, Aéroports de Paris, 1999. Light-weight 'peninsula' roof.

▲ **7.57** Tension-spokes allow frames to wrap around the floor slab.

▲ **7.58** Learning Resource Centre, Thames Valley University, Slough, England, Richard Rogers Partnership, 1996. The two exterior forms.

In the progression towards examples of visually heavier detailing two buildings are visited that incorporate instances of both light and heavy detailing. The Learning Resource Centre, Slough, consists of three forms – a main rectilinear concrete-framed block housing bookcases, seminar rooms and offices; a light-weight curved roof enclosing a three-storey volume; and within it, a single-storey concrete structure whose upper floor accommodates computing and study areas (Fig. 7.58).

Detailing for lightness is most evident in the curved roof structure, although vertical posts at each end of the light-weight structure are



▲ 7.59 Lightened by the use of tension-ties, the curved beams arch over a computing area.

▲ 7.60 Faculty of Law Building, Cambridge, England, Sir Norman Foster and Partners, 1996. The light-weight façade structure contrasts with the concrete columns.

▲ 7.61 Raking concrete columns with a 'softening' sand-blasted finish.

generously penetrated. The curved primary beam depths are kept to a minimum. Ties that connect to intermediate points along the beams effectively deepen them structurally without increasing their visual mass (Fig. 7.59). Beam legibility, already reinforced by a bright yellow finish, is further enhanced by concealing roof purlins behind the perforated ceiling cladding. The typically dimensioned solid beam and column members of the reinforced concrete frames provide the contrasting heavy detailing.

The Faculty of Law Building, Cambridge, also illustrates both light and heavy detailing (Fig. 7.60). Curved vierendeel trusses form a triangulated-lattice vault structure to the fully glazed north-facing wall. Springing from ground level and propped horizontally at third floor level, the vault rises another two storeys to curve back to a line of support towards the far side of the building. The vault structural members are so much lighter than the substantial raking columns that support approximately half the total floor area of the building (Fig. 7.61).

Examples of exposed structure that are detailed to accentuate a sense of heaviness rather than lightness are rare in contemporary buildings given a general preoccupation with transparency and its offer of light and views. The chunkiness evident in some contemporary footwear and motor vehicles is yet to find wide acceptance architecturally. The visually heavy structural detailing at the Centre for Understanding the

▲ **7.62** Centre for Understanding the Environment (CUE), Horniman Museum, London, England, Architype, 1997. Front façade with chimney-columns.

Environment (CUE), London, is a consequence of its ecologically sustainable design, rather than any other reason. Primary structural members are hollow, exemplifying the highest possible level of structure and services integration (Figs 7.62 and 7.63).[16] Structural members function as air conduits in this naturally ventilated building. Column and beam cross-sections are therefore larger than expected for a building essentially of domestic scale, even accounting for the weight of its turf roof. Warm air is extracted through circular penetrations in the triangular cross-section plywood web-beams, and channelled horizontally to columns. Columns that terminate above roof height as chimneys, move air vertically. For such a relatively small building the structural members appear heavy.

▲ **7.63** Interior column and beam.

Plain to decorative

LaVine describes the exterior ground floor columns of the iconic Villa Savoye, Paris (Figs 7.64 and 7.65), as 'classically placed but unadorned, slender cylinders, reflecting a technological stance of the twentieth century'.[17] Consistent with the plainness of the columns, the floor beams are rectangular in both cross-section and elevation. Their widths that equal the diameters of the columns and result in tidy beam–column junctions, are evidence of attention to detailing that does not seek attention.

A more recent building illustrates the potential for structural detailing with decorative qualities to enhance architecture. The ribbed concrete

▲ **7.64** Villa Savoye, Paris, France, Le Corbusier, 1929. The front and a side elevation.

▲ **7.65** Plain exterior column and beam detailing.

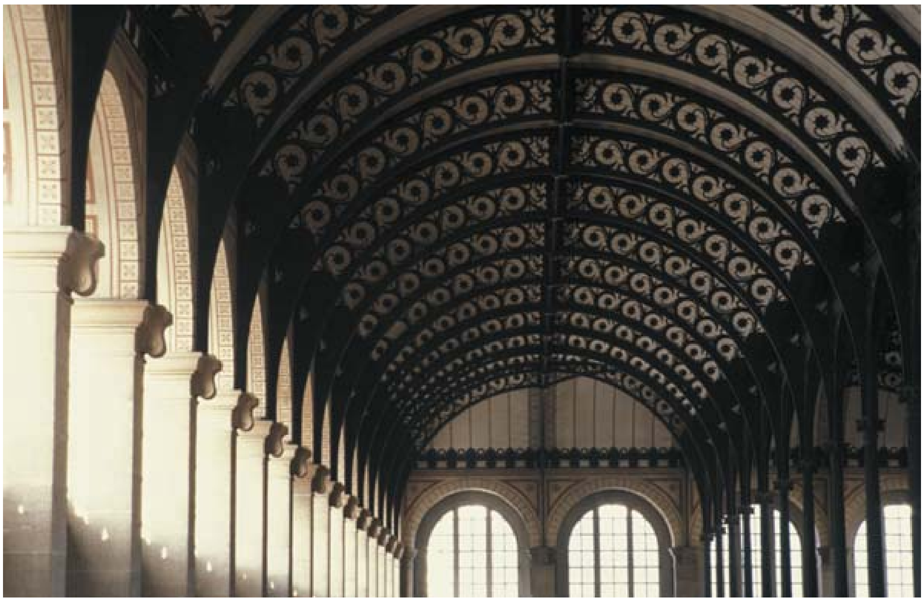
▲ **7.66** Schlumberger Extension building, Cambridge, England, Michael Hopkins and Partners, 1992. Exposed ribbed soffits around the perimeter.

floor soffits of the Schlumberger Extension building, Cambridge, are reminiscent of the isostatic ribs indicating lines of constant stress in the concrete slabs designed by Pier Luigi Nervi in the 1950s (Fig. 7.66). Floor construction at Cambridge was achieved using permanent ferro-cement formwork, subsequently infilled with reinforced concrete. Continuing the ribbed theme on the façade that is achieved by the closely spaced tubular columns, the sculptural qualities of the concrete ribs enrich the visual appearance of the cantilevering soffit.

The exquisitely detailed wrought-iron beams of the Bibliothèque Sainte-Geneviève, Paris, also provide a fine example of decorative structural detailing (Fig. 7.67). A flowing pattern resembling stars and sickles replaces the standard diagonal web members that usually join top and bottom chords. Here, structural detailing and artistry merge in these much admired members.

The Hamburg Museum Courtyard Canopy, Hamburg, provides the final example of decorative structural detailing. A fully glazed grid-shell structure roofs an L-shaped courtyard (Fig. 7.68). Pairs of 6 mm diameter pre-tensioned cables form a triangular mesh to stiffen the orthogonal grid, fabricated from 60 mm by 40 mm steel section. Commenting upon the architectural qualities of the canopy, Holgate explains:

> *The problem of diagonal bracing members competing for visual interest with those of an orthogonal grid has been solved by the lightness of the prestressed cables which here form a delicate accompaniment to the stronger lines of the steel slats. As usual, much thought has been given to the details both from an architectural and technical standpoint. These are an essential element in the success of the roof. The project is an excellent*



▲ **7.67** Bibliothèque Sainte-Geneviève, Paris, France, Henri Labrouste, 1850. Curved iron beams over the reading room.

outcome of the quest for lightness, delicacy, minimalism, and unobtrusiveness in structure.[18]

While the designers tried to minimize the visual impact of most details, one in particular stands out. In three locations, and most importantly where the two arms of the L-shape meet in the corner and the roof bulges beyond its normal barrel forms, additional tensile stiffening maintains the cylindrical geometry. Vertical fans of cables radiate upwards from a central plate suspended high above the courtyard floor and held in physical and visual equilibrium by an inverted V-shaped tension cable. A stainless-steel plate whose roundedness echoes that of the vaulted form above, its shininess, the fan-like layout of cables and intricacy of connectors between plate and lower cable, all create an impression of a necklace-like piece of jewellery (Fig. 7.69).

▲ **7.68** Hamburg Museum Courtyard Canopy, Hamburg, Germany, Von Gerkan, Marg and Partner, 1989. General view of the canopy.

Summary

Having defined structural detailing as the configuration, shaping and finishing of members and their connections, the chapter explores how detailing makes significant architectural contributions to buildings.

First, it examines the expressive and responsive nature of structural detailing. An analysis of observed structural details suggests that most express or respond to some aspect of the building of which they are part. Examples illustrate details that relate to architectural form, building function, materiality and construction, and structural actions.

▲ **7.69** The fan detail possesses the aesthetic qualities of a piece of jewellery.

Detailing that expresses structural actions can either express bending or other stress, or articulate structural connectivity like clamping or clasping. Some sources of detailing inspiration lie completely outside the building and its programme.

The second and final section of the chapter illustrates the huge diversity of the aesthetic qualities of structural detailing. Each detail suggests its own architectural reading and influences its surrounding architecture. Detailing qualities are categorized into the following four broad groupings – refined to utilitarian, simple to complex, lightness to heaviness, and plain to decorative.

The multiplicity of examples, the sheer diversity of expressive and responsive details, and the different aesthetic qualities of details indicate the enormous potential for exposed structural detailing to enhance the realization of architectural concepts.

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