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Structure as Architecture, Architects as Engineers

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Abstract: The construction challenges and opportunities demand a new kind of professional, with expertise in structural analysis, architectural design, systems engineering, information technology, and management. A decision has to be made regarding the extent to which structure should be exposed in an architectural design. For doing the right choice the architects should have a very good knowledge of structural engineering concepts and materials applications. Structural exposure should be limited to buildings where structure integrates with and clearly strengthens the expression of architectural ideas. Having a huge number of structural possibilities, designers and architects have considerable freedom of choice. In this article we try to make a short description of the potential of structure that is beams, columns, frames, struts and other structural members, to enrich architecture. We try to raise architects' perception of structure and materials as integral elements of architecture rather than applied technologies.

Keywords: engineering, architectural, materials, design, structure, technology.

1 Introduction

Building design is as old as the history of civilization, yet today the evolving challenges and opportunities in building design and construction are real, diverse, and exciting.

- New building materials, including composites, super-high-strength concrete, adaptive, self-monitoring and self-healing systems.
- Total integration of information technology in building life cycles, using building information models to support design, construction, operation, and rehabilitation.
- Evolving requirements for safety and security, including damage-resistant and resilient materials and designs.
- Life cycle designs that support adaptive reuse of structures as needs change.
- Demands for energy efficiency and sustainability, including use of recycled materials and zero-energy building concepts.

These challenges and opportunities demand a new kind of professional, with expertise in structural analysis, architectural design, systems engineering, information technology, and management.

2 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 color, 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. 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 (Fig. 1 and Fig. 2).

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.



Fig. 1. The main concourse. United Airlines Terminal, Chicago, USA, Murphy/Jahn, 1987.



Fig. 2 Beam-column junction.

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.

3 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’. 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. 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. 3). 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 (Fig. 4). Their diagonal web members increase in diameter as they approach the truss supports in response to the increasing value of shear force. At the Stratford Regional Station, London, structural actions similarly inspire expressive detailing (Fig. 5). 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.



Fig. 3 Beam geometry expresses the bending moment diagram. Jussieu University, Paris, France, Edouart Albert, 1965.



Fig. 4 Double-chords reduce the visual mass of the truss. Centre Pompidou, Paris, France, Piano and Rogers, 1977.

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 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.



Fig. 5 Curved frames spring from cast-steel bases. Stratford Regional Station, London, England, Wilkinson Eyre, 1999.

4 Conclusions

We have to encourage a broad, creative and critical stance towards structure. It presents an alternative approach to some current practice where the most expedient structural engineering solution is adopted unless its impact upon the architectural concept is considered to be disastrous. For structure's potential as an enlivening architectural element to be realized, collaboration between the architect and the structural engineer needs to be extensive and intensive.

Architects need to take an active role in all stages of structural design, working with the structural engineer in order to achieve mutually acceptable outcomes. Beginning with preliminary structural layouts through to detailed design at working drawing stage, both groups of professionals together need to wrestle with the various options. Structure is owned by both professions and it must satisfy simultaneously the requirements of both – load-bearing as well as architectural expression.

We have to bridge the gap between both professions.

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