CONCRETE ARCHITECTURE – ROLES OF EXPOSED STRUCTURAL ELEMENTS AND FORMS

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ABSTRACT

Exposed reinforced concrete structural systems or components can make a major aesthetic contribution to the architecture of a building. In a recent Research and Study Leave, mainly in Western Europe, the author studied seventy-five buildings with significant exposed concrete structure. From this selection, approximately twenty buildings stand out by the manner in which their structural systems are so prominent architecturally. In each case exposed concrete structure is a primary architectural language of the building. Due to their quality of architectural design, both in concept, detail and quality of construction, these buildings are excellent examples of the potential for exposed structural concrete to play important architectural roles.

INTRODUCTION

During a recent period of Research and Study Leave, mainly in Western Europe, the main research theme was to further an ongoing investigation into how structure – structural elements and systems, can contribute more fully to architecture. Preparation for the trip involved visual scans of all books and periodicals less than six years old in the School of Architecture library. The search was for buildings whose structures are doing more than just resisting loads. Building owners were contacted and an itinerary prepared. Each building studied, to some degree, has received architectural recognition by virtue of being reviewed in the architecture literature.

This paper reports on buildings where exposed concrete structure is an indispensable and major architectural component. Buildings are selected to first show a variety of concrete architectural structural systems, and secondly, to illustrate how these systems can become significant architectural elements. Although in most cases the primary role of structure is to resist load, in this analysis that role is taken for granted. Architectural contributions of structure are the focus of attention.

The nine different structural systems and elements the paper discusses are:

- Moment resisting frame,
- Cantilever,
- Arch,
- Strut,
- Catenary,
- Wall (and slab),
- Beam,
- Column, and
- Shell.

Clearly, although a number of structural systems such as grillages, trusses and types of spatial structures are not listed, their potential for architectural expression is undiminished. For example, as far as concrete trusses are concerned, one recalls the concrete vierendeel trusses that are primary structural and architectural elements of the landmark La Grande Arche building (1989), La Defense, Paris. The fact that the list is truncated reflects the limited number of buildings studied.

Like all exposed structure, concrete structure can contribute to architecture in many ways other than just resisting gravity and lateral load. As can be seen from the following case studies, structure also plays important functional, aesthetic and symbolic roles. Each structural system is discussed in turn with emphasis on its non-structural roles.

MOMENT FRAME

Vancouver Public Library

The building consists of two contrasting forms. An elliptical wall containing reading areas wraps around the rectilinear main library area that houses book stacks and administrative functions. Both forms are supported by reinforced concrete frames that speak totally different architectural languages.
Perimeter wall opens to reveal main building frame members

Perimeter walls, evocative of the Roman Colosseum, appear to be post and beam construction. Horizontal joints delineate posts from beams, and vertical joints suggest each beam element is simply supported. While precast concrete elements did in fact form a trabeated exterior framework temporarily during construction, cast-in-place reinforced concrete construction now ties elements into moment resisting frames in orthogonal directions. Exposed junctions between the two types of concrete reveal and explain the construction approach.

In stark contrast, the main building moment resisting frame structure is detailed as such. In three locations, including along one whole façade, gaps in the perimeter wall reveal monolithic beam and column moment frame construction.

Learning Resource Centre, Thames Valley University

Reinforced concrete frames are dominant visual features of the main three story rectangular block. Plain off-the-form column and beam finishes contrast with flush dark coloured glazed infills. This contrast increases visual clarity of the structural system, allowing it to modulate exterior facades with its simple rectilinear pattern. Horizontal construction joints that mark the beam depth across column faces are small enough not to be too noticeable and don’t reduce the monolithic character associated with moment frames.

Frame geometry modulates three story facades

The architectural theme of frames continues inside the building. An absence of infills between columns reveals member thicknesses. Open and fully exposed, frames enable free movement between the 'lean-to' space and the main block. Now, the columns in particular, modulate space rather than surface, providing a regular order that is reflected in the bookshelf spacing nearby. They also set up another contrast; this time between relative massiveness and natural materiality of columns, and fine, curved and brightly coloured steel half-portals.

Church at Porta
Briassago, Switzerland., designed by R. Cavadini, 1997.

Three identical two storey high frames in the transverse and longitudinal directions define the architecture of this church. Columns and beams have the same dimensions and are of square cross-section. Within an all encompassing cube, frames create eight small cubes. Of these, the rear four house the main church space. Compared to the previous building, these frames subdivide space more actively and uncompromisingly. For example, the mid-height beam in the central frame passes right through the interior church space. As it penetrates, it divides the volume into two – separating sanctuary from congregational area. In so doing it provides a reminder of the
architect’s harsh rational architectural design approach.

Frames define cubes within a cube
Reinforced concrete walls provide enclosure. Inside, frame members are separated visually from walls by negative horizontal triangular recessed joints and by surface finish. Frame members are distinctive with their smooth finish as compared to the textured off-the-form boarded finish for walls. On the exterior, grey stone block veneer, flush with frame members, provides a slightly clearer distinction between frame and infill.

This is a very simple building. Certainly, by imposing such a rational and ordered geometry, moment frames dominate the architecture. They also raise the question as to whether such a rational approach is suited to the building use.

CANTILEVER

Bilbao airport
Bilbao, Spain, designed by Santiago Calatrava, 2000.

Precast concrete cantilever brackets
Several frame bases are exposed within the terminal waiting room. They are painted blue and support precast concrete brackets using the same detailing language. Brackets cantilever out, extending the terminal area beyond the main building line. At first glance, the cantilevering forms appear to be steel, but upon inspection it is clear they are precast concrete. The architect has exaggerated the size of pin connections between A-frames and cantilevering brackets. Different pin diameters reflect differing levels of load transfer. Exposed pin surfaces are expected to be oversized compared to internal pin diameters in order not to weaken the brackets unduly. The form, materiality and connections of these cantilevers are unusual but totally harmonious with the extensive use of precast concrete framework elsewhere.

Deep curving cantilever ribs
Huge cantilevering ribs dominate the ground floor entry area. They support forecourt and roading of the departure level above.

Approximately three metres deep at their maximum, ribs taper towards their tips where their depths equal the thickness of the supported concrete slab.

Although these reinforced concrete cantilevers occur in one area only, their form links with the admired ribbed aesthetic throughout the complex, inside and out. Their gentle curved soffits are consistent with noticeably curved structural members in the main terminal space.

Ferry terminal
Hamburg, Germany, Alsop and Stormer, 1993.
The structural form, for a building that mainly provides office accommodation, consists of repeated pairs of tapering single bay precast concrete frames on either side of simply supported beams. On the land side, cladding conceals structure, but on the harbour side, two storeys of precast concrete frames are exposed.
Canary Wharf Station

Ribs cantilever off spine beam
Cantilevers make a significant aesthetic contribution to the roof of the main station space, the ticket hall. In this long high volume a central row of elliptical reinforced concrete piers support a longitudinal spine beam. In section the beam soffit curves up a short distance until a deep and wide recess signals a change in curvature. From this level upwards the roof slab curves outwards, cantilevering out on each side to form the roof that supports an outdoor park above. Curved paired ribs also cantilever from the spine and are spaced regularly along its length to provide additional roof support. The overall effect is a roof shaped like outstretched wings.

All architectural detailing is very refined. Negative joints modulate all concrete surfaces and both acknowledge yet conceal construction joints.

ARCH

Oriente station
Lisbon, Portugal, designed by Santiago Calatrava, 1998.

Reinforced concrete arches aligned parallel to train tracks support platforms above the main station. In all, the structure below platform level consists of ten rows of arches, each row consisting of five successive overlapping arches. Arches therefore dominate and enclose this multi-storeyed station. You are aware constantly of their presence. Arch spans determine widths of major spaces, and suspended walkways thread through arches where they overlap. Stairs and escalators pass up between bifurcating arch ribs near their bases. The skeletal quality of arches contributes spatial complexity and an openness that facilitates flows of people, light and air.

Structural members are rounded or generously chamfered in section to lessen their visual mass. Grey concrete surfaces make the station quite dark, but given Lisbon’s Mediterranean climate this might be appropriate, and certainly easier on the construction budget than using white cement.

STRUT

Museo de les Ciencies (Science museum)
Valencia, Spain, designed by Santiago Calatrava, 1998.

Branching struts of structural ‘trees’
Even though attractive shallow arches provide structural support for large areas of the museum, reinforced concrete structural ‘trees’ are the most spectacular architectural elements. Five massive piers slope almost indiscernibly inwards to support a series of segmented arches where five strut clusters fan out in three dimensions to support concourse and main roof ribs. This is a tangle of structure. It is visually very complex, yet due to its detailing, also elegant, perhaps possessing some characteristics of a regal crown. Tapered and chamfered members join at rounded transitions. Exposed structure certainly follows the Gothic formula of increased complexity with height. Here, and especially on a longitudinal façade, Calatrava’s standard approach of introducing unnecessary complexity for the sake of aesthetic effect borders on over elaboration.

On the exterior, full height struts slope over the main entry area to buttress and brace the roof. They form a dynamic sloping plane that overcomes the undesirable effect of an otherwise vertical multi-storey wall. White concrete structural members are dominant throughout the museum.

Law Courts

Inclined struts support courtroom pods

The most interesting aspect of this complex is how courtrooms are individually expressed as conical shaped pods. Exterior and interior surfaces are timber, but precast construction provides floor soffits and inclined struts that elevate pods above concourse level. As well as their supporting function, struts define informal waiting and meeting areas.

Courts are usually noted for their conservative and classical architectural styles. But in Bordeaux, eight sloping precast concrete struts under each courtroom introduce a dynamic and informal character. From some vantage points visual order disappears. Struts appear to be assembled chaotically. However, there is nothing chaotic about the quality of precast concrete work. Its standard of detailing and finish is very high.

Church of St. John the Baptist
Florence, Italy, designed by Giovanni Michelucci, 1968.

Sloping struts contribute to the complexity of the church’s exterior form. Even their unusual buttressing action does not prepare visitors for the amazing array of interior irregular struts supporting the roof.

Irregular strut orientation and detailing

Members, of square or rectangular cross-section with off-the-form finishes, are very unconventional but immensely intriguing. Given that the church is a monument to lives lost during construction of Italy’s modern motorway system, its structures raise questions about what they symbolize – trees perhaps, or are they subtle abstractions of construction scaffolding or other construction equipment like cranes?

Most reinforced concrete members are detailed with irregularities, perhaps a single taper, or tapers to each end from some point along their lengths. Sometimes, one or more surface areas are recessed, often in a rounded shape or else...
cross-sections suddenly change part way along a member. This detailing strategy bestows uniqueness upon each strut. Here is concrete structure, light years away from rational, economic, repetitive and efficient construction, that pays tribute to architectural creativity and concrete constructional skill.

CATENARY

Portugese Pavilion
Lisbon, Portugal, designed by Alvaro Siza, 1998.
Not since the 1962 Dulles International Airport Terminal has a reinforced concrete catenary aroused so much architectural interest. At Lisbon it is shallower than its predecessor and its lightness of colour makes it less oppressive from underneath. However, exposure of its primary tension steel sets it apart.

Catenary and buttress connection detail
At one end of the catenary, where it connects to a gently inclined diaphragm that transfers forces to vertical buttresses, designers remove the concrete in which tension cables are normally embedded. Light filters between rods, highlighting their presence and expressing their tension-resisting role. Essentially, this is a simple building comprising of three structural systems. All are visible - walls, diaphragm and catenary, with catenary the most striking.

WALL AND SLAB

Faculty of Journalism
Pamplona, Spain, designed by Vicens and Ramos, 1996.
Long narrow horizontal and vertical slots penetrate large areas of exterior concrete wall elevations. Apart from a few circular columns and horizontal slabs, no other significant structural elements are visible. Interior design follows the same pattern. All vertical surfaces are concrete walls of equal thickness. Structure creates a simplicity and plainness. Fortunately, all spaces are generously proportioned and wall placement and floor level variation achieves intriguing interior spaces.

An architecture of walls
Walls perform multiple functions. Their structural repertoire extends beyond bearing wall and shear wall action to beam action. As an example, walkway bridge balustrades extend from walls, spanning gaps, and then function as normal balustrades along corridors above the main concourse. Since almost every surface is concrete, it has been lightened in colour. The contractor has risen to the challenge of pouring such large areas of exposed concrete by achieving a high quality finish.

Kunsthaus
Bregenz, Austria, designed by Peter Zumthor, 1997.

Minimal structure
This museum of modern art is a unique example of a minimalist approach to structure. Its structural plan is most impressive. The entire gravity and lateral load supporting structure consists of only three reinforced concrete walls placed around the building perimeter. At ground floor level, all three walls are visible, grey backdrops to works of art. Four
rows of recessed formwork ties and joints and square ceiling formwork joint patterns reflect the means of construction.

Positioning walls near the exterior leaves spacious gallery areas but also necessitates significant two-way structural actions in floor slabs that span the building plan. Structure contributes a simplicity, bareness and plainness to the interior. Environmentally, it functions as a huge thermal stabilizer and volume through which heating and cooling water pipes pass.

Beams, due to their materiality and dimensions appear to be structural members, but don’t in fact perform significant structural functions. If these members were constructed of painted dry framing, their impact would be lessened significantly. Their powerful expression of uprootedness and disorientation, emphasised by their concrete materiality, would be largely lost.

**BEAM**

**Jewish Museum**  
*Berlin, Germany, designed by Daniel Libeskind, 1999.*

Beams as symbolic elements

Although the fractured and fragmented form of the museum building is not generally reflected in its largely concealed structure, in one area concrete beams play a powerful symbolic role. Above main stairs to the major exhibition area, beams pass chaotically across the space; at different angles, shapes and dimensions. Structure symbolizes clearly the major disruptions, upheavals and disasters experienced by German Jews.

**COLUMN**

**Public University of Navarra**  
*Pamplona, Spain, designed by Javier Sáenz de Oíza, 1990*

Colonnades define circulation

Two large columns with haunched capitals designate entry to the central block. They are precursors to its columnar interior architecture. Colonnades with columns at 1.5m centres screen off internal lobbies and define circulation routes. To pass through a lobby you walk through two rows of columns that function like screens or filters.

Truncated conical haunched capitals decorate each column. This ubiquitous detail strengthens the role of columns as a unifying design motif.

**Crematorium**  
*Berlin, Germany, designed by Axel Schultes Architects, 2000.*

The most memorable aspect of this building is its main hall and clustered columns. In some places columns are separated by only 1m, but in others, particularly alongside the four enclosing walls, larger column free spaces are found. Apparently random column spacing creates many different spaces within the
volume, each possessing a sense of intimacy for a given group size, from two to thirty people. This is sombre architecture, but one that responds to human grief.

Randomly placed columns create a unique space

Randomness of column spacing contrasts with rational and orthogonal architecture elsewhere in the building, and perhaps echoes the confusion and lostness felt by many mourners. Yet, at the same time, people can find comfort in the strength and stability of columns whose presence completely dominate the space.

Natural light enters through gaps between circular holes in the concrete ceiling slab and the columns. A short and relatively narrow stub beam connects column to slab. Light, introduced in the vicinity of a structurally critical connection, washes down column surfaces and accentuates their aesthetic contribution to the crematorium hall.

**SHELL**

**Millennium Seed Bank**  

It is appropriate for a building that stores and protects seed collections to be protected by a husk-like roof. Simple moment resisting frames support thin reinforced concrete barrel vaulted roofs.

Exposed concrete structural elements order and unify the complex. This results in a restful and calming influence. In this example of design simplicity, each member and detail pared back to its essence and completed with an excellent standard of concrete finish.

**SUMMARY**

Each structural system is illustrated by one or more buildings whose architecture represents, to a significant degree, both a celebration of that system and of reinforced concrete as an architectural material. The study highlights the diversity of concrete structural forms and their ability to contribute architecturally. Case studies are a reminder of how reinforced concrete is suitable for a wide range of structural systems and components. Its suitability for varying degrees of environmental exposure is also apparent. Given that concrete can be exposed entirely within the building envelope, can function as the envelope, or play a role in both situations, its potential for unifying a design through minimizing the numbers of building materials can not be underestimated.

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