AESTHETICS OF ARCHITECTURAL STRUCTURE AND SERVICES INTEGRATION

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SUMMARY

This paper explores the aesthetic potential of architectural structure and services integration. Literature that considers the integration of these two systems is not extensive, however a brief historical overview shows how appropriate integration of structure and services can make significant aesthetic contributions to architecture where structure is exposed. Observations of several exemplary contemporary buildings suggest that integration can help achieve structural clarity, introduce aesthetic delight into construction details and lead to expressive structural and architectural forms. These architectural works, that feature different levels of structure and services integration, suggest that where integration is a primary architectural design objective, there is considerable potential for structure to exhibit fine aesthetic properties.

INTRODUCTION

Integrating disparate client aspirations, architectural ideas, building elements and systems is the essence of architectural design.While meeting many diverse design requirements, an exemplary work of architecture is usually characterised by a sense of unity. A clear architectural vision provides the conceptual framework for the incorporation and unification of all elements, including building systems. The architect strives to achieve the desired performance objectives, in terms of cost, functionality, and also aesthetically.

This paper examines how appropriate integration of structure and services may contribute aesthetically to architecture. Accepting the definition of architecture originating from Vitruvius (Morgan 1960) as "firmness, commodity and delight", the focus of this study is on *delight* as distinct from the more pragmatic concerns of architecture. While functional aspects of integration have already been well discussed by others, (Bovill 1991) for example, this exploration focuses on examples of structure and services integration that exhibit design qualities that set them apart from most contemporary practice.

Before considering integration both from an historical and contemporary practice perspective, the literature is reviewed briefly.

LITERATURE REVIEW

Given the importance of integration to architectural design, and the desirability of some degree of structure and services integration, it is unexpected to discover how little has been published on the subject. Perhaps it is a reflection on how most professional effort is confined to those mainstream areas within a discipline. Certainly, structural engineering literature gives scant mention of integrating structure with mechanical services, and vice versa; neither from a functional nor an aesthetic perspective. Architectural historians display a similar lack of interest, given their preoccupation with issues of space, form and planning. The dearth of building environmental critique within the architectural tradition, and the consequent marginalization of the significance of mechanical services has been outlined clearly and redressed by Banham (1969). In his history of building environmental modification he provides several examples of structure and services integration.

Collins (1965) also raises the subject explicitly but briefly. He identifies Auguste Perret as the first architect to achieve complete integration in a building, and cites Louis Khan's art gallery at Yale University (1954) as another successful example of integration. However, it is surprising that in one section of Collins's book, where he examines how interest in biological ideas has affected architectural thought and practice, he provides few references to how nature has or could be a source of architectural inspiration for structure and services integration. The human body is surely one of the most highly integrated systems known. Consider how the essential life maintenance functions of red blood corpuscle production and mineral storage are encapsulated within skeletal bone structure. It appears that this potentially rich source of biological inspiration for integration, relevant for both theorists and practitioners, has been neglected.

The Building Systems Integration Handbook (Rush 1986) presents the most comprehensive consideration of integration. It contains a wealth of information about integration from a practical perspective and categorizes various levels of physical and visual integration. Focussing on the building systems described as structure, envelope, mechanical and interior, the Handbook defines and describes five levels of integration. These are summarised in Table 1, beginning at the most basic level, and finishing with the highest level of *unified* integration, and are used throughout this paper. With respect to visual integration, the *Handbook* defines five levels of increasing visual complexity (Table 2).

Level	Description
Remote	Complete physical separation
Touching	Systems touch, but are not permanently connected
Connected	Permanent connection of systems
Meshed	Systems interpenetrate or occupy the same space
Unified	The same construction material simultaneously fulfills more than one function

Table 1 Summary of integration levels

Level	Description
1	Structural or mechanical system is not visible (hidden by a ceiling, for example)
2	System is visible but its appearance has not been modified
3	System is visible and its texture or colour changed
4	Size or shape of a system altered
5	Orientation or location of a system is different from that normally expected

Table 2 Levels of visual integration

These levels only describe the visual status of an individual system element, such as a column or duct. Although each level represents the degree to which the normal visual appearance of an element has been modified, it does not describe the visual interrelatedness of differing systems. For example, it does not help an assessment of the aesthetic quality of a rectangular duct attached to a circular or tapering column. Unfortunately, issues of aesthetic quality, or *delight*, or notions such as elegance and consistency that are at the heart of *delightful* architecture, and the focus of this paper, are not addressed. A similar observation may be made of other writings on the integration of structural and environmental systems (Bovill 1991, Kilminster 1991). Both are concerned with satisfying building code requirements and give little attention to exploring the potential for structural and services integration to be exploited architecturally.

HISTORICAL OVERVIEW

Examples of *unified* integration of structure and services can be found in ancient buildings. Clay tile risers or chimneys embedded in walls functioned as heat distributors in Roman baths (Donaldson 1994). Possibly other less significant examples may be found in buildings of all early architectural periods. The open channel rain water disposal drains forming the upper surfaces of the Gothic flying buttresses, at Notre Dame Cathedral in Paris, is one such example.

During the many centuries that load bearing masonry was the most dominant construction method, the most common example of structure and services integration remained the embedment of chimney flues, and later, ventilation ducts, in walls. This example of *unified* integration, where the walls fulfilled two functions simultaneously, was also adopted in early concrete house construction. The walls of the first concrete house built in the United States of America, the Ward House of 1873, consisted of two panels separated by a space up to 250 mm wide for heated air to pass through (Elliott 1992). Such innovations, however, were not without their problems. The following comment made in 1875 by an experienced English architect serves to highlight the well-recognised potential difficulty of maintaining and repairing *unified* systems: "the use of concrete produces an inconvenience which nobody would suspect without experience of it, viz. that unless flues are lined with pipes or panelled with very exceptional care, the smoke will percolate through the walls and issue in distant parts of the house wherever any part of the wall is not plastered" (Collins 1959).

Similar difficulties were experienced in Paxton's Crystal Palace, London, 1851, which incorporated several innovative examples of *unified* integration. McKean (1994) reports water leaking through many first floor column to balustrade connections when blockages occurred in the hollow cast-iron column rain water drainage system. Also, the post-tensioned and cambered wooden "Paxton gutters", fulfilling three roles as truss top chords, exterior gutters and interior condensation channels, proved susceptible to deterioration.

Some years earlier, in 1801, saw the first attempt to use hollow cast-iron columns as steam conduits for internal heating at the Twist Mill building near Manchester (Ackermann 1991). The success of this seemingly sensible and visionary idea was lessened by unspecified problems arising from "column expansion" (Elliott 1992). Early industrial architecture also provides a fine examples of *meshed* cast-iron structure integration where belt drives pass through columns.

As mentioned previously, Auguste Perret is credited as the first architect "to achieve complete integration" (which he accomplished in his Museum of Public Works, Paris in 1938) (Collins 1965). Pairs of perimeter columns sit astride transverse grid lines and "the blank spaces between were filled with precast panels both inside and out, set far enough apart to contain all the heating and ventilation ducts. There was thus no mechanical apparatus to obstruct the ceilings..." (Collins 1959).

Most of these features were not new. Some thirty four years earlier in Buffalo N.Y., Frank Lloyd Wright had incorporated them into his Larkin Administration Building. Renowned for its visually strong external form, a high level of structure and services integration was included among its many design innovations. The client required concealment of all services including mechanical ventilation. Both structure and services were hidden behind fire resistant masonry cladding, reducing visual evidence of the high degree of integration. At the corners of the atrium, double steel columns provided space for vertical ducts, and double steel floor beams formed the sides of horizontal exhaust air ducts (Quinan 1987). This building is the forerunner of many with structure and services integrated using pairs of columns (and beams)

The art gallery at Yale University (1954), designed by Louis Khan, is acknowledged for the quality of its integration. It is ironic that the celebrated integrative opportunity afforded by the reinforced concrete tetrahedral units floor structure was in fact discovered by chance (Scully 1962). Voids within the structural form allowed pipes, ducts and electrical wires to be run horizontally with such freedom that the exposed floor and ceiling structure was described as a "breathing ceiling". This example of integration may have been in Khan's mind when he stated: "In Gothic times, architects built in solid stones. Now we can build with hollow stones. The spaces defined by the members of a structure are as important as the members" (Frampton 1995).

Khan continued to develop horizontally *meshed* integration in the Medical Research Laboratory, Philadelphia, 1961. Floors were supported by orthogonal grillages of precast concrete vierendeel trusses, allowing the many services uninterrupted runs. Although physical integration was provided, the need for visual or aesthetically acceptable integration was not attended to in enough detail. Khan insisted upon reinstallation of some of the services for the sake of visual order (Komendant 1975).

Possibly the first example of architectural form to express a similarly high level of integration is the Yamanashi Press and Radio Centre, Kofu, Japan (1964), designed by Kenzo Tange. Sixteen hollow cylindrical shafts support all gravity and lateral loads, and most incorporate ducts and vertical circulation. Other well known buildings with similar expressive forms are the Knights of Columbus Building, New Haven, Connecticut (Orton 1988) and the City Telecommunications Centre by Tange (1988). However, in both later examples, the reinforced concrete structural corner shafts are supplemented by conventional interior structure.

Reinforced concrete is also the construction material for some impressive European projects where integration of structure and services was a stated architectural objective. In two factories for Olivetti, designed by Marco Zanuso, structural shape responds to requirements of integration (Zanuso 1971). At Merlo, Argentina, horizontal services are housed in circular hollow reinforced concrete beams supported by columns shaped and penetrated for services functionality (Figure 1). Integration is expressed candidly in some areas by air-conditioning units supported by, and plugged into beam ends. The structural detailing at the second factory at Marchianise, Italy, is less expressive of its integrative role, yet exposed structural elements still provide a strong and elegant visual impact. Single storey factory precast concrete roof beams with inverted Y cross-sections are supported by cantilever columns. Column width decreases with height to allow pipe work to run along and under sloping beam flanges. The facade composition is enriched by expressing perimeter columns and beam cross-sections on the exterior.

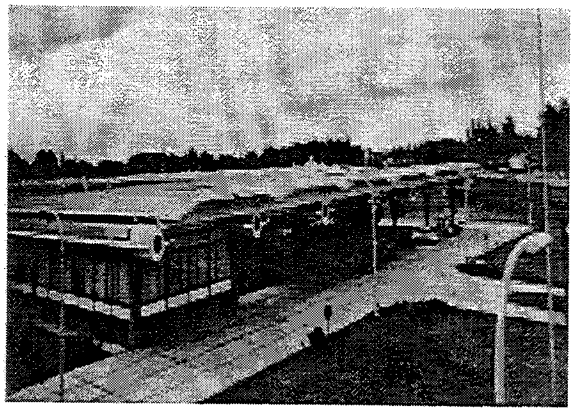

Figure 1 Expressed hollow reinforced concrete beams

Although many fine examples of integration are hidden, integration can provide architecturally expressive opportunities. One example is where tubular steel members have been water filled to provide fire resistance. In the Mercantile Bank Building, Kansas City (Rush 1986) columns are water filled, and at the Centre Pompidou, Paris, Silva (1994) reports that water filled exposed steelwork is integrated in the same *unified* manner.

OBSERVATIONS OF CONTEMPORARY BUILDINGS

In exemplary works of architecture with exposed structure, structure and services integration is usually carefully considered. The following observations suggest how appropriate integration may enhance architecture.

Structural Clarity

Where an architectural concept demands building envelope transparency or clear structural expression, either *remote* integration or a much higher level such as *meshed* or *unified* is necessary. Visual expression of exposed structure should not be compromised by visible secondary or tertiary structural elements, building services or other building components.

Uncompromising clarity is a feature of two recent London buildings. At the Mound Stand, designed by Michael Hopkins and Partners, nothing detracts visually from the flowing form expressed by the fabric and seams of the membrane roof (Figure 2).

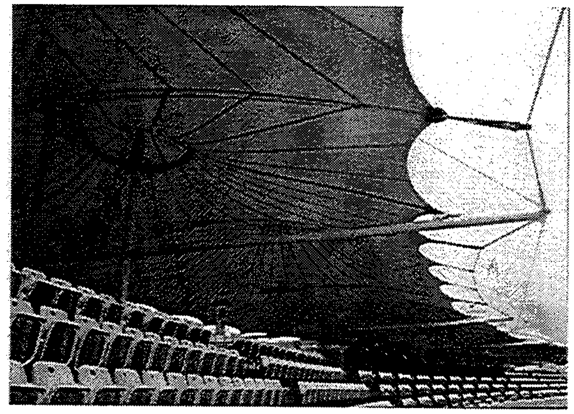

Figure 2 Structural clarity of the Mound Stand canopy structure

Similarly, at Foster Associates' Stansted Airport Terminal, both the intended building transparency and the visual impact of the attractive shallow triangulated roof domes are achieved by *remote* integration. All services, signs and other fixtures are floor mounted and compactly *meshed* within tubular steel roof structure frames supporting inclined roof struts (Powell 1992) (Figure 3). Such well executed integration is often taken for granted.

Figure 3 *Meshed* and *remote* integration at Stansted Airport

It is therefore of interest to reflect on two older architecturally significant buildings with dominant structural forms where a *connected* integration strategy has been employed. At Nervi's Palazetto dello Sport, Rome, the arresting interior feature is the striking pattern formed by the precast ribs as they flow from the oculus to perimeter buttresses; a synthesis of structure and art. Unfortunately the visually intrusive suspended sound and light equipment gantry is disappointing since it detracts from the surrounding geometrical purity. One hopes that if it were to be redesigned, either a *remote* or a *unified* integration strategy would improve visual structural clarity.

To a lesser extent the design concept of the long-span convex hanging concrete roof structure of the Dulles International Airport, designed by Eero Saarinan (1958-62) is also compromised. A centrally located opaque element connects the roof with ground. It encloses rain water disposal and internal roof access, but an aesthetic cost is paid as the visual purity and conceptual simplicity of the scheme is diminished.

Aesthetic Delight in Construction Details

Exposed construction details can be a source of aesthetic delight. Zanuso's circular hollow and inverted Y beams have already been referred to, but several other examples are instructive.

A *unified* approach to integrating structure and lighting is one of many integrative design features at the Stadelhofen Station, Zurich (1990). In the provision of natural and artificial lighting in curved concrete surfaces, engineer-architect Santiago Calatrava produces delightful curved ends to slender ribs and tear drop light voids (Figure 4).

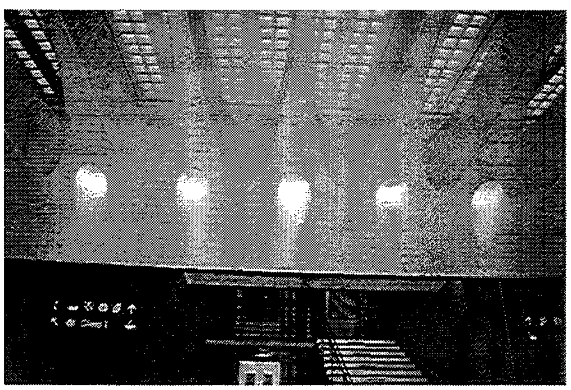

Figure 4 Integrating structure and light at Stadelhofen station

Bracken House, London (1991), designed by Michael Hopkins and Partners features more visually restrained integration. Quadrant shaped hollow columns function both as air ducts and provide seating for radiating precast concrete floor beams and define the internal corners of the atrium. An innovative *meshed* integration scheme positions suspended floor slabs at beam mid-heights to yield minimum interstorey heights (Berry 1992).

Unusual *meshing* cast-steel beam to column connections at the Lyon School of Architecture, designed by Jourda and Perraudin, accommodate the difficult requirement of passing a down-pipe of approximately the same size as the structural member through an area of support. Although the down-pipes are found only in selected areas, the detail is repeated throughout the first floor (Figure 5).

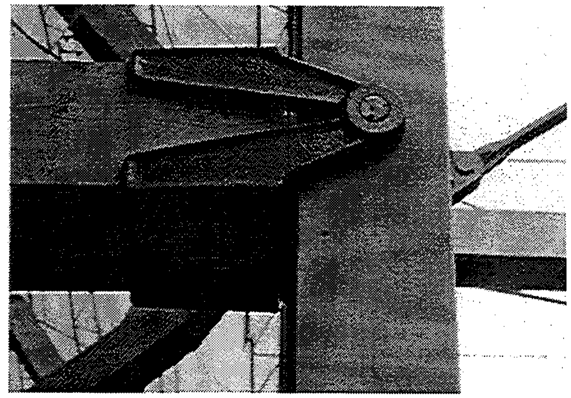

Figure 5 Beam-column connection to accommodate a vertical pipe to the left of the column

Expressive Structural and Architectural Forms

Distinctive structural form and detailing can result especially where *unified* integration is an architectural design objective, as has been seen in work by Zanuso and Khan. Integration, as a primary architectural goal, has the potential to provide new and expressive architectural forms. Because structural members that incorporate high level integration will by necessity be of large and of uncommon cross-section, they will be visually dominant, and therefore have the potential to become celebrated architecturally.

CONCLUSION

Integration of structure and services is but one aspect of the integrated design approach required in architecture. Where structure is exposed, and the level and methods of integration are appropriate, the resulting forms and details can enrich the aesthetic dimensions of architecture considerably.

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