Integration: Structure and Envelope

Integrated Building Systems

Part I: Integration Principles

Part II: Structure and the Exterior Envelope

Part III: Integration Case Studies
Building Systems: Definitions

1. Foundation/Subgrade (*SITE*)
2. Superstructure (*STRUCTURE*)
3. Exterior Envelope (*SKIN*)
4. Interior Partitions (*SPACE PLAN*)
5. Mechanical Systems (*SERVICES*)
6. Furnishings (*STUFF*)

Sources:
Also see Turner, Gregory, *Construction Economics and Building Design*

[Image by MIT OCW.]
Building Systems

Building Systems: Definitions

1. Foundation/Subgrade (SITE)
2. Superstructure (STRUCTURE)
3. Exterior Envelope (SKIN)
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6. Furnishings (STUFF)

Rush specifies only four systems;
  - Structure
  - Envelope
  - Interior
  - Mechanical

Source: Rush, Richard,
The Building Systems Integration Handbook
Integration Levels

Definitions

1. Remote: systems are physically separated from one another but yet still coordinated functionally

2. Touching: One system rests on another

3. Connected: one system is mechanically fastened and dependent on another

4. Meshed: systems occupy the same space

5. Unified: systems share the same physical elements

Five Levels of Integration
Image by MIT OCW.
Performance Mandates

Performance is, generally, the measurement of achievement against intention.

1. Spatial Performance
2. Thermal Performance
3. Indoor Air Quality
4. Acoustical Performance
5. Visual Performance
6. Building Integrity

Building Example

Integration of:

1. Exterior envelope (also secondary structure)
2. Mechanical Services (Lighting)

Level of integration: MESHED

Strategy:

Using aerogel as a translucent insulation that provides thermal resistance to the exterior envelope as well as allowing natural light to illuminate interior spaces.
Part II: Structure and the Exterior Envelope

Exterior Envelope Issues: stressors

**Solar Radiation**
- heat gain/loss

**Wind and Air Pressure Differentials**
- air infiltration/exfiltration

**Moisture**
- vapor
- condensation, dew point
- snow, rain and ice
- hydrostatic pressure (basement)

**Temperature Differentials**
- thermal gradient
- freeze-thaw cycle
- differential thermal expansion
- thermal bridging

**Extreme Weather**
- hurricanes
- tornados
- lightning

Image by MIT OCW.
## Structural Issues: stressors

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<th>Static</th>
<th>Live Loads</th>
<th>Occupancy</th>
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<tr>
<td></td>
<td>Dead Loads</td>
<td>Environmental (snow, water)</td>
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<td></td>
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<td>Self-weight of structure</td>
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<td></td>
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<td>Fixed Building Elements</td>
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<td>Forces due to</td>
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<tr>
<td>settlement,</td>
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<tr>
<td>thermal effects</td>
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<table>
<thead>
<tr>
<th>Dynamic</th>
<th>Continuous (oscillating-uniform or regular)</th>
<th>Seismic forces</th>
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</thead>
<tbody>
<tr>
<td>Lateral loads</td>
<td>Wind forces</td>
<td></td>
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<tr>
<td>Impact (discrete, e.g. blast)</td>
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<td>Internal Forces</td>
<td>Structural Element</td>
<td>1 dimension</td>
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<td>-----------------</td>
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<tr>
<td>1. Compression</td>
<td>column</td>
<td>buttress</td>
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<td>strut</td>
<td>flying buttress</td>
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<td></td>
<td>wall</td>
<td>arch</td>
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<td></td>
<td>barrel vault</td>
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<tr>
<td>2. Tension</td>
<td>tie</td>
<td>catenary</td>
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<td></td>
<td>cable</td>
<td>suspension bridge</td>
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<td></td>
<td>hanger</td>
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<td>3. Bending</td>
<td>beams</td>
<td>egg-crate</td>
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<td>one-way slab</td>
<td>two-way slabs</td>
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<td></td>
<td>portal frames</td>
<td>(flat, ribbed, coffered, etc.)</td>
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<td>4. Shear</td>
<td>plate action</td>
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<td>5. Torsion</td>
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<td>6. Bearing</td>
<td>pin</td>
<td>bearing plate</td>
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Opportunities for Integration: Structure and Exterior Envelope

The exterior wall and structural frame form the assembly at the edge of the building. Therefore, the integration of the two systems has the capacity to:

- transmit natural light into the interior
- allow for the natural servicing of the building
- increase the efficiency with which individual materials and components are used
- reduce the weight of the building
- reduce thermal bridging (note on positioning of the exterior wall)
- reduce the exposure of the superstructure elements to the weather
- reduce differential movement between the skin and the structure
- reduce geometric coordination conflicts
- extend the life of the building by effectively addressing the weather enclosure

...and ultimately
- reduce the material expenditure
- reduce the time expenditure
- reduce spatial needs
Structure: Guiding Principles of Analysis and Design

Lightness
Maximum Lightness achieved by minimum use of materials.

Maximum Diversity/Minimum Inventory
Element design.

Construction Logic
Awareness and optimization of the construction sequence.

Economy
Constraints are good.

Systemic Thinking
Understanding and pursuing ideas regarding what the entire structure is doing.

Scale of the Building.
Scale of the Joint.
Structure: Lightness

Equalize stress in all members

The result of equalizing stress in elements of the same material is a minimal use of the total material used.

Buckminster Fuller, Biosphere.

Image Courtesy of Nicolas Janberg of Structurae.
Structure: Maximum Diversity/ Minimum Inventory

Element Design
Joint Design
Structure: Economy

Constraints are good
Anything can be built with enough $
Lowest total cost wins
Structure: Seismic Design

Lateral Forces
Hazards

Direct
Surface Fault Ruptures
Ground Shaking
Ground Failures
Liquefaction
Lateral Spreading
Landslides

Indirect
Tsunamis
Floods
Fires
Structure: Seismic Design

Superstructure should be light.

Building plan should be simple, symmetric and regular.

Superstructure should be symmetrically loaded.

Continuous distribution of mass, stiffness, strength, ductility.

Column-Beam alignments should be coaxial, as much as possible.

Horizontal structural elements should always fail first.
(Turkey 08.18.99)

Relatively short spans and avoid cantilevers.

Non-structural components should either be integrated or well separated.

Superstructure should have largest possible number of defense lines.

Stiffness and strength of the superstructure should be compatible with the foundation.
(Taiwan 09.20.99)
Developing Materials/Processes

I believe we can rethink the way we can use many materials, especially how they are detailed, to express more clearly their engineering nature, and thereby find a new and interesting aesthetic.

Peter Rice
Developing Materials/Processes

Composite Structural Elements

Image by MIT OCW.
Part III: Integration Case Studies

Integration Possibilities

Case Studies

Two-System Combinations

1. Structure and Envelope
   Glenn Murcutt: Houses

2. Structure and Illumination
   Louis Kahn: Kimbell Museum

Three-System Combinations

3. Structure, Illumination and Envelope
   Behnisch and Partners: General Assembly and Annex of Bundestag

4. Structure, Envelope and Services
   Sir Norman Foster: Stansted Airport

5. Structure, Services and Illumination
   Sir Norman Foster: Sainsbury Gallery

6. Structure, Mechanical and Illumination
   Sir Norman Foster: AMAir Museum

7. Structure, Envelope and Construction Process
   Arato Isozaki: Palais de Congres

Four System Combinations

8. Structure, Envelope, Mechanical and Illumination
   Sir Norman Foster: Reichstag

see Rush, Chapters 6 and 7
Case Study 1: Two-System Integration
Structure and Services

Structure
Lightweight/columnar metal structure

Services
Natural ventilation
Kinetic exterior wall elements
Metallic roof finish for reduction of nighttime heat loss

From Glenn Murcutt, Buildings and Projects, Francoise Fromonot

“... The regional geology, hydrography, climate and direction of the prevailing winds determine the house’s positioning, its structure, and the greater or lesser porousness of the facades receiving breezes necessary for ventilation. The sun’s angle of incidence in different seasons determines the dimensions of the roof overhang, which cut off the vertical rays of the sun in summer while the height of the façade’s upper glazing allows the low winter sun to penetrate the heart of the interior... Thus the façade is a result, not an articulated formal composition by the architect.”
Case Study 2: Two-System Integration
Structure, Illumination

Structure
Cycloid vaults supported by columns
Not acting as a vault nor as a series of arches the cycloid form facilitates a structure that behaves more like a curved beam resting on columns and a terminal arch

Illumination
Natural Light
Provided by a central divide in the cycloid vaults
Also, the structure allows for openings along the lower edge of the end support-arches.
Case Study 2: Two-System Integration
Structure, Illumination

- a. Sheet lead roof
- b. Acrylic skylights
- c. Post-tensioned concrete shell
- d. Reflectors
- e. Supply ductwork
- f. Incandescent track lighting
- g. Wood flooring
- h. Return air ducts
- i. Exposed concrete masonry
- j. Waffle slab
- k. Travertine infill

Image by MIT OCW.
Case Study 3: Three-System Integration
Structure, Envelope, Illumination

**Structure**
Steel frame building

**Envelope**
Various glass and metal enclosure elements

**Illumination**
Various natural daylighting techniques

Behnisch and Partners
General Assembly and Annex of
German Bundestag, Bonn
Case Study 4: Three-System Integration
Structure, Envelope, Services

Structure
Steel tube and cable modular unit as basis for building design

Services
Air supply and return located at these structural bays and integrated into design

Envelope
Premanufactured roof elements lifted whole onto the structural modules

Also, notice the “spoilers” along the roof edge meant to redirect the concentration of air pressure on this part of the roof.

Also
Illumination
Natural light diffusers incorporated into roof elements

Image Courtesy of Ludwig Abache and Structurae.
Case Study 4: Three-System Integration
Structure, Envelope, Services

Images Courtesy of Ludwig Abache and Structurae.
Case Study 5: Three-System Integration
Structure, Services and Illumination

**Structure**
3-dimensional steel tube trusses: wall and roof construction

Allows for interstitial space to run mechanical equipment
Spans are greatly increased thereby foregoing interior columns

**Services**
Mechanical equipment and distribution networks are contained within the interstitial space created by the structure

**Illumination**
As the building is composed of a panelized system natural light can be brought into the space at any point along the skin of the building.
Case Study 6: Three-System Integration
Structure, Envelope and Illumination

Structure
Precast and cast-in-place concrete construction produces a shell with of large span

Envelope
Concrete mass minimizes the diurnal temperature swing within the interior

Illumination
Allowed into the space through an edge condition and vertical glass wall
Case Study 8: Four-System Integration
Structure, Services, Envelope and Illumination

**Structure**
Parliamentary Hall steel roof structure

**Services**
Naturally Ventilated
Utilizing existing natural ventilation flues incorporated into the original building in the 1890s, the parliamentary chamber is naturally ventilated.

Also, the heat and power generators are fueled with a refined vegetable oil, derived from sunflower seeds. This has produced a 94% reduction in carbon dioxide emissions.

**Envelope**
Serves to allow for natural ventilation and lighting

**Illumination**
Natural light is reflected down into the Parliamentary Hall using a series of faceted mirrors attached to the central service cone.
Case Study 8: Four-System Integration  
Structure, Mechanical, Envelope and Illumination

Buildings now account for $\frac{1}{2}$ of energy use in the western world.  
$\frac{3}{4}$ of the world’s annual energy output is presently consumed by $\frac{1}{4}$ of the earth’s population.