Integration: Structure and Envelope

Integrated Building Systems

Part I: Integration Principles

Part II: Structure and the Exterior Envelope

Part III: Integration Case Studies

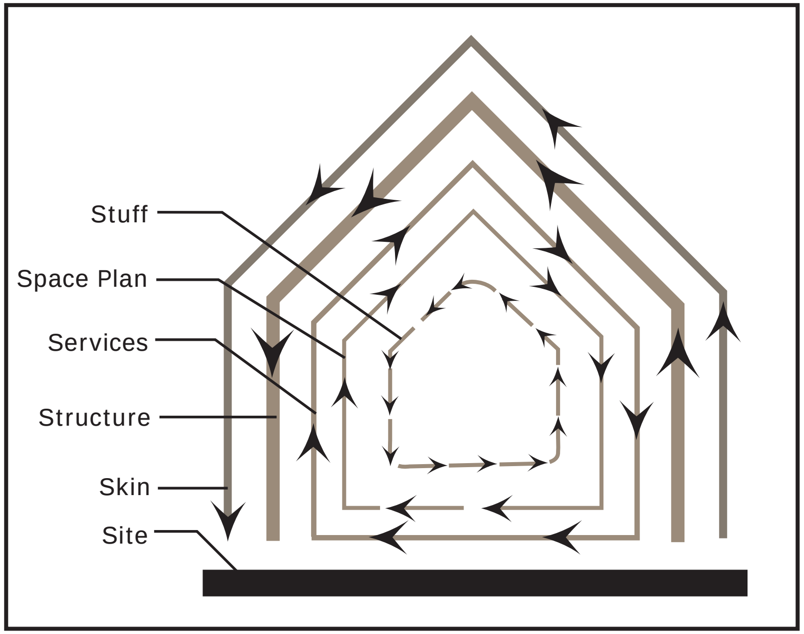
Building Systems

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:
Brand, Howard,
How Buildings Learn.
Also see Turner, Gregory,
Construction Economics and Building Design

Daly, Genik: Valley Center, CA, 2000.



Bensonwood Timber Frame: 1996.

Image by MIT OCW.

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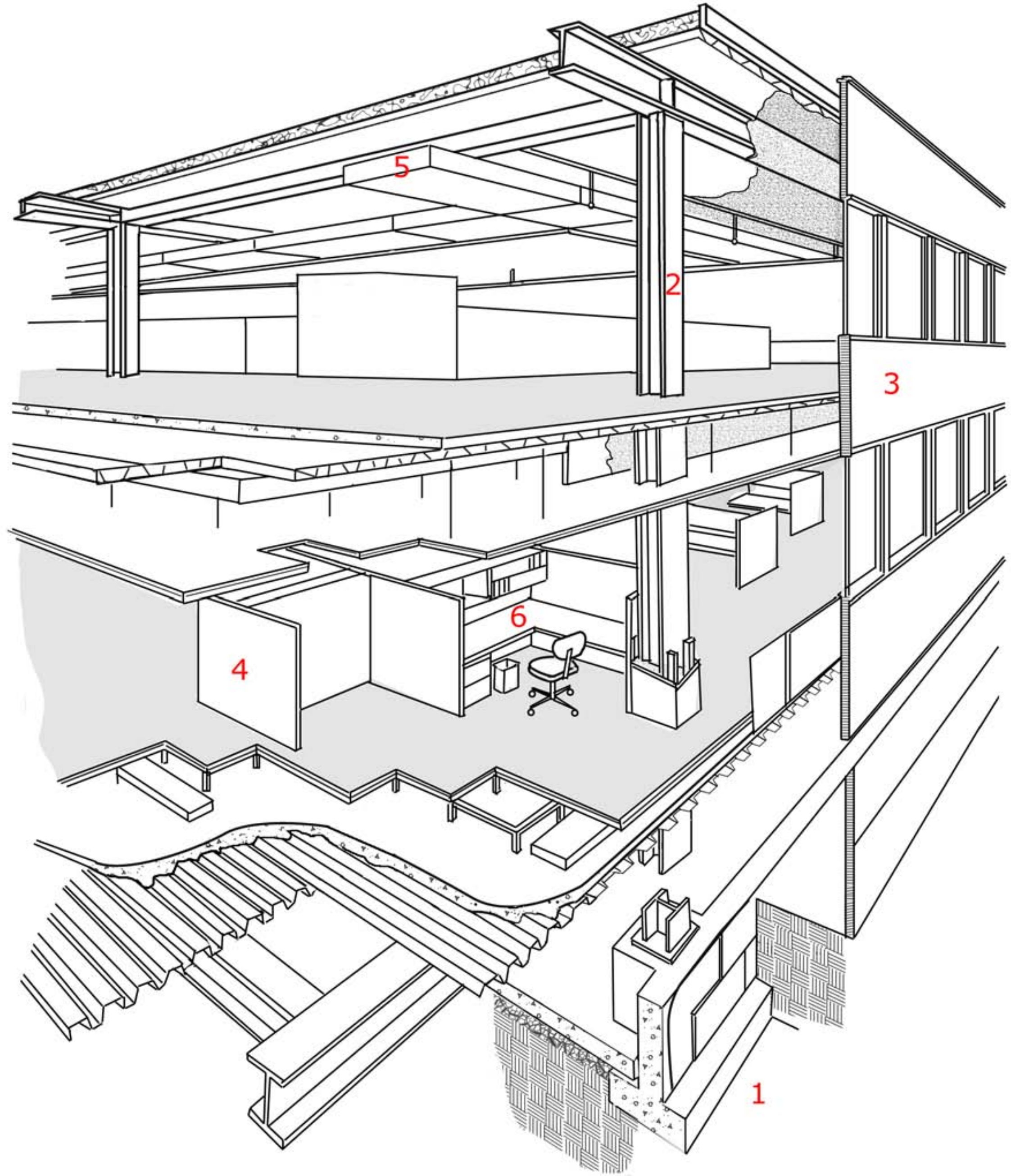
Rush specifies only four systems;

- *Structure*
- *Envelope*
- *Interior*
- *Mechanical*

Source: Rush, Richard,
The Building Systems Integration Handbook



Curtainwall and raised floor construction.

Image by MIT OCW.

Integration Levels

Definitions

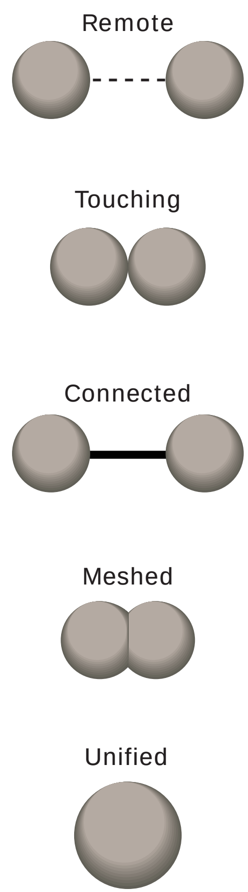
1. Remote: systems are physically separated from one another but yet still coordinated functionally

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.

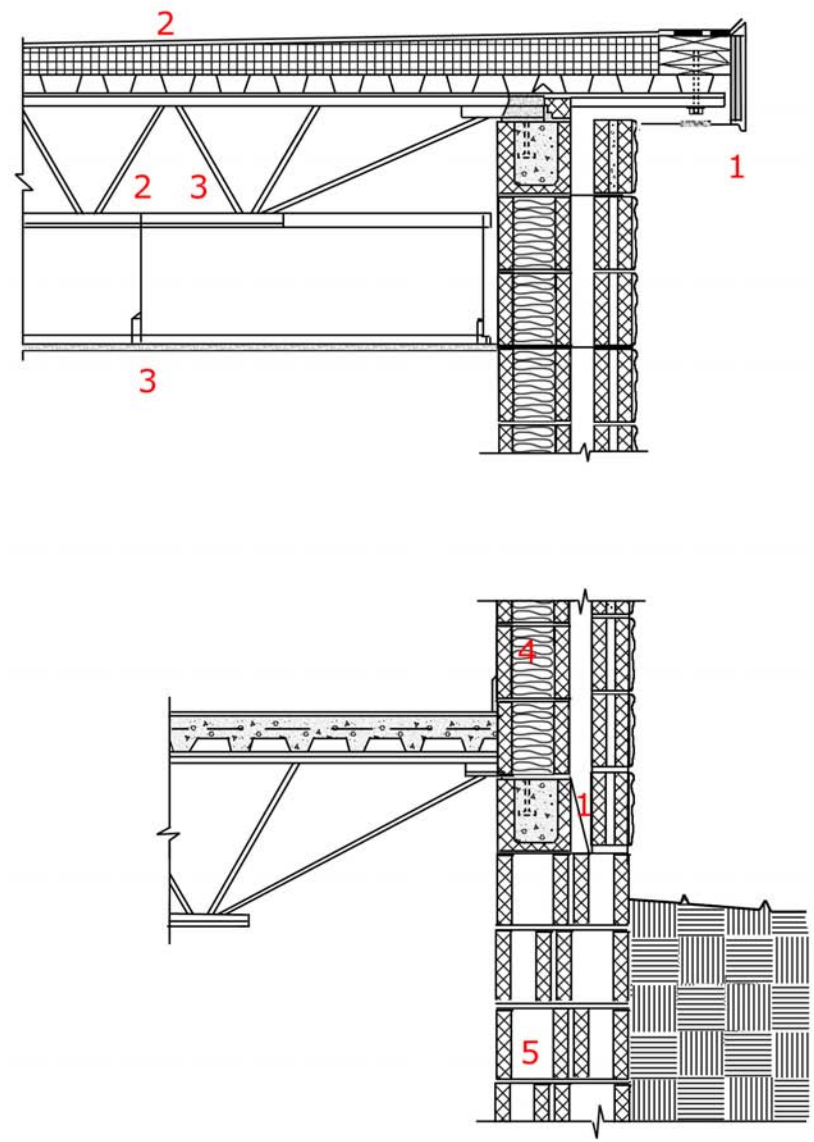


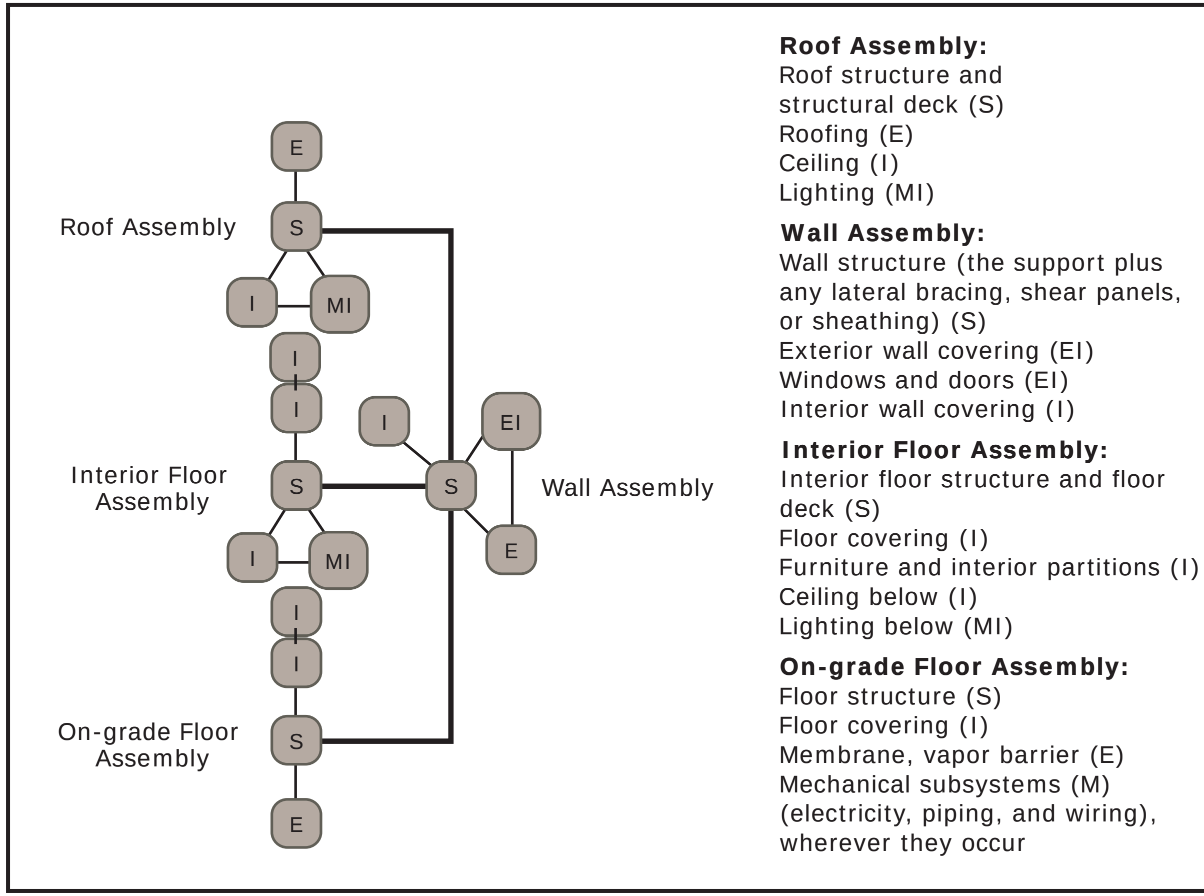
Image by MIT OCW.

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

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



Integration diagram

Image by MIT OCW.

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.

Thomas Herzog, Aerogel Exterior Envelope System

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
tornadoes
lightning

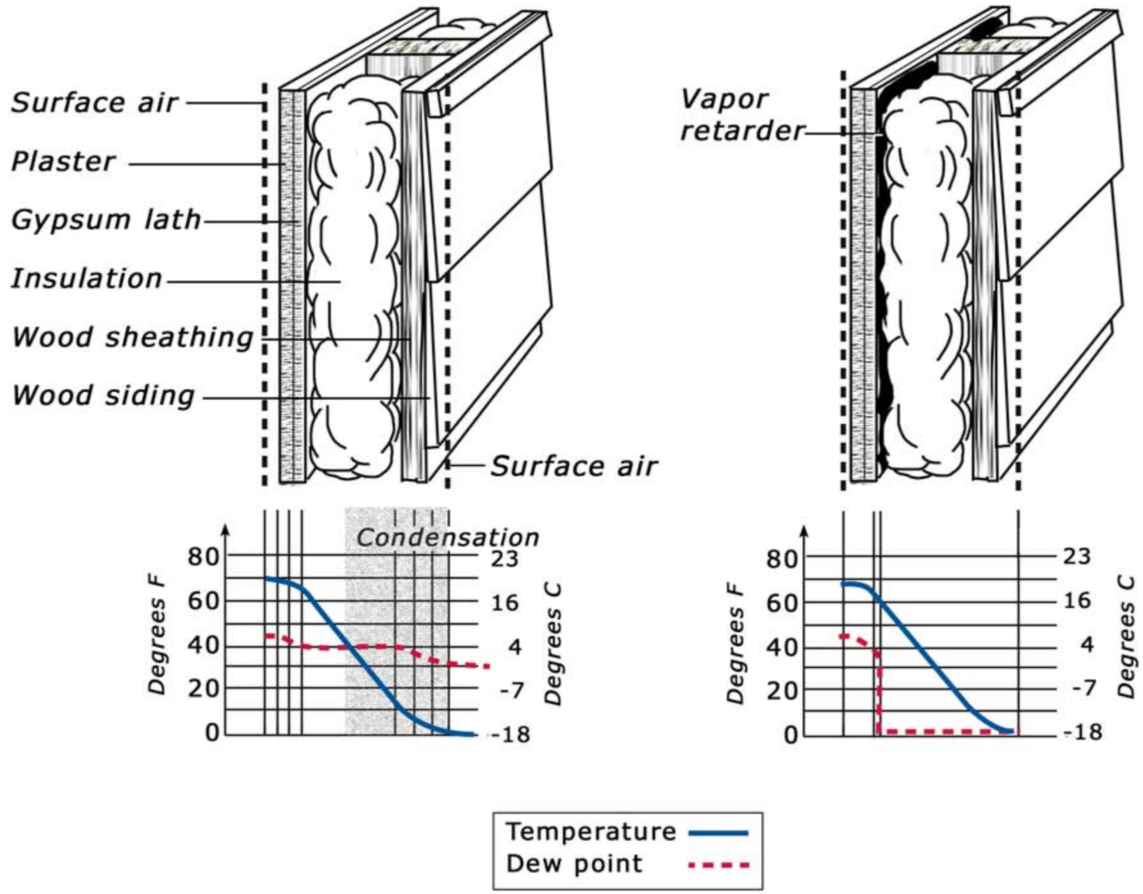


Image by MIT OCW.

Structural Issues: stressors

Static	Live Loads	Occupancy
		Environmental (snow, water)
	Dead Loads	Self-weight of structure
		Fixed Building Elements
	Forces due to settlement, thermal effects	
Dynamic	Continuous (oscillating- uniform or regular)	Seismic forces
	Lateral loads	Wind forces
	Impact (discrete, e.g. blast)	

Structural Actions

External Stressors produce Internal Forces

Internal Forces	Structural Element 1 dimension	2 dimension	3 dimension
1. Compression	column strut wall	buttress flying buttress arch barrel vault	ribbed vault fan vault dome thins shells grid shells
2. Tension	tie cable hanger	catenary suspension bridge	shear-free assemblies (bubbles, cable nets, shear resistant fabrics, membranes)
3. Bending	beams one-way slab portal frames	egg-crate two-way slabs (flat, ribbed, coffered, etc.)	frames
4. Shear	plate action shear wall	plate action shear wall	folded plates torsion
5. Torsion	n/a	n/a	cross-bracing
6. Bearing	pin	bearing plate	moment connection

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 the total material used.

Buckminster Fuller, Biosphere.

Image Courtesy of Nicolas Janberg of Structurae.

Structure: Maximum Diversity/ Minimum Inventory

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

Design Strategies

Structure: Seismic Design

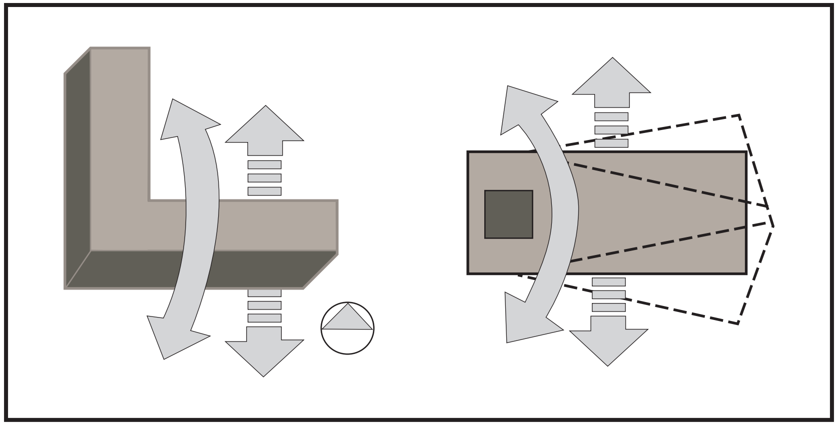


Image by MIT OCW.

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.

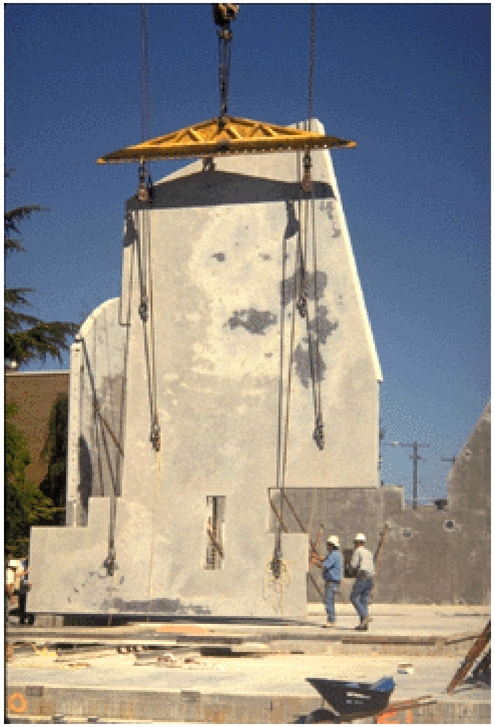
Peter Rice

- Glass
- Carbon Fiber
- Cellulose
- Panels: e.g.stress skin

Processes

Concrete

- Tilt-Up Slab
- Rapid Curing



Developing Materials/ Processes

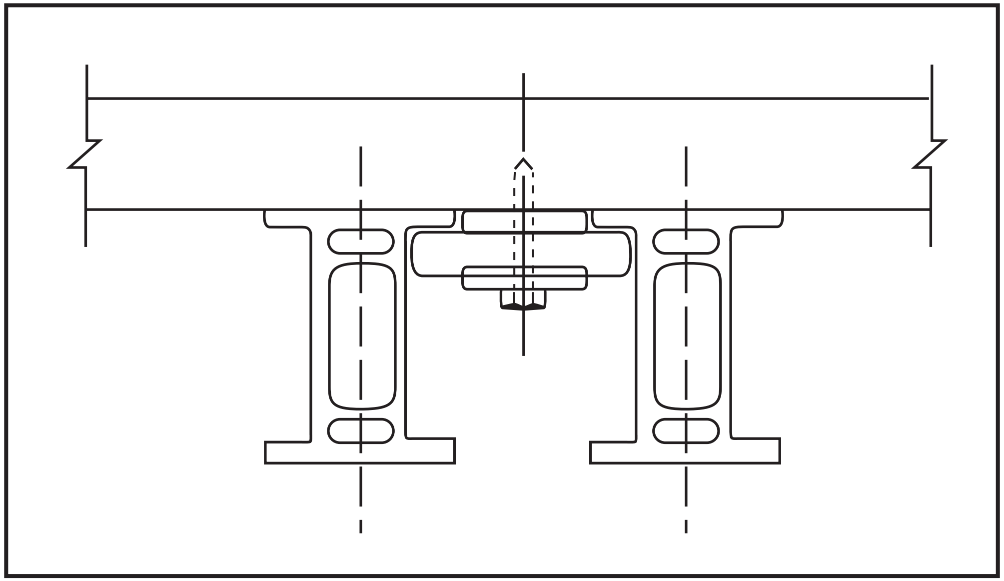


Image by MIT OCW.

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.”

Louis Kahn
Kimbell Art Museum

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

Louis Kahn
Kimbell Art Museum

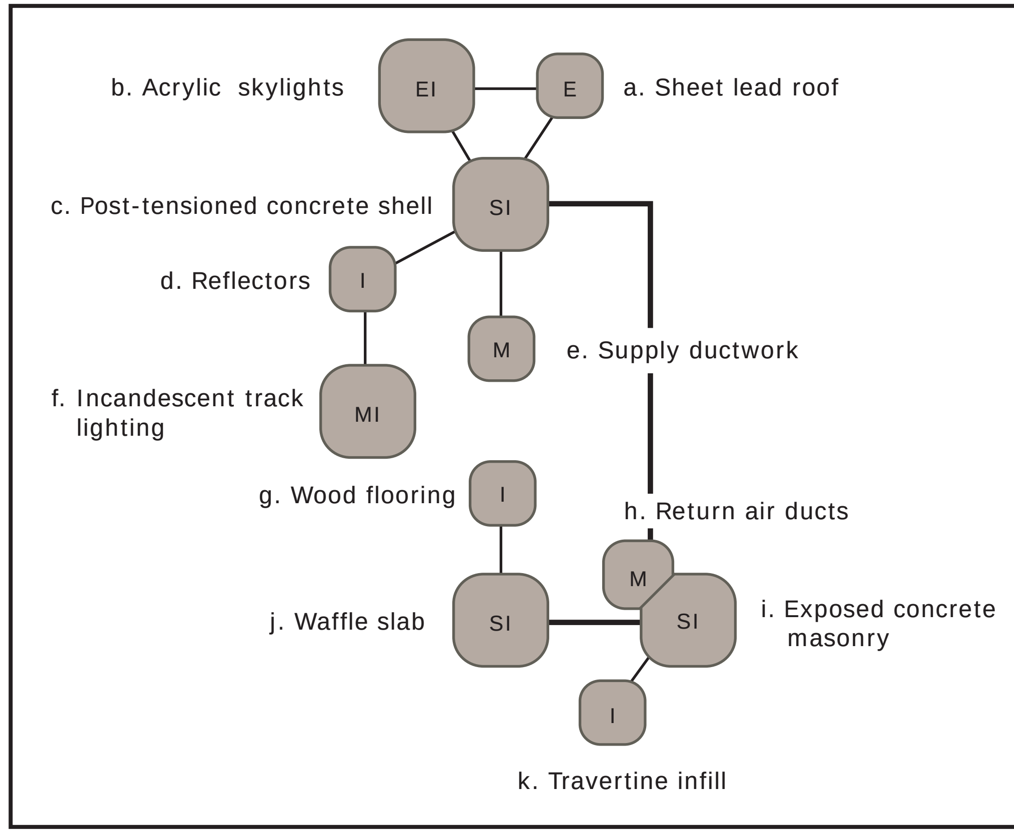


Image by MIT OCW.

Behnisch and Partners

General Assembly and Annex of German Bundestag, Bonn

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

Case Study 4: Three-System Integration
Structure, Envelope, Services

Norman Foster
Stansted Airport

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.

Image Courtesy of Ludwig Abache and Structurae.

Also

Illumination

Natural light diffusers incorporated into roof elements

Case Study 4: Three-System Integration
Structure, Envelope, Services

Images Courtesy of Ludwig Abache and Structurae.

Norman Foster

Sainsbury Gallery

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

Sir Norman Foster
American Air Museum

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

Sir Norman Foster
Reichstag

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.

Sir Norman Foster
Reichstag

Case Study 8: Four-System Integration
Structure, Mechanical, Envelope and Illumination

Buildings now account for ½ of energy use in the western world.
¾ of the world's annual energy output is presently consumed by ¼ of the earth's population.