Complexity, Simplified

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Complexity, Simplified

Advances in digital technologies over the past 20+ years have radically increased the tendency to design complex structures. For steel, this has expanded the use of highly angular geometries, curves, and Architecturally Exposed Structural Steel.

In keeping with the thought behind the category system for AESS that describes a range of approaches to the detailing of projects, this talk will look at a range of methods to address the design of complex steel structures. There are many ways to achieve *aesthetically driven visual complexity* and some can be *economically driven*.

Learning Objectives

- Understand what drives complexity in architectural steel design
- Understand what constitutes complexity in architectural steel design
- Understand the enhanced importance of good communication within the design team (architect, engineer, fabricator)
- Understand that there are types of complex steel
- Understand that complexity is normally visually driven
- Understand that there are choices that can be made to arrive at lower costs

What **Drives** Complexity in Architectural Steel?

- It is predominantly an **aesthetically driven act**
- It responds to stylistic concerns
- It has been facilitated by expanding digital capabilities in the AEC industry
- It gets more and more complex (chaotic and unusually curved steel elements) simply "because it can"
- For the most part fabrication has been able to keep up with the aesthetically driven desires of Architects
- But it certainly adds to the cost of the project

What **Constitutes** Complexity in Architectural Steel?

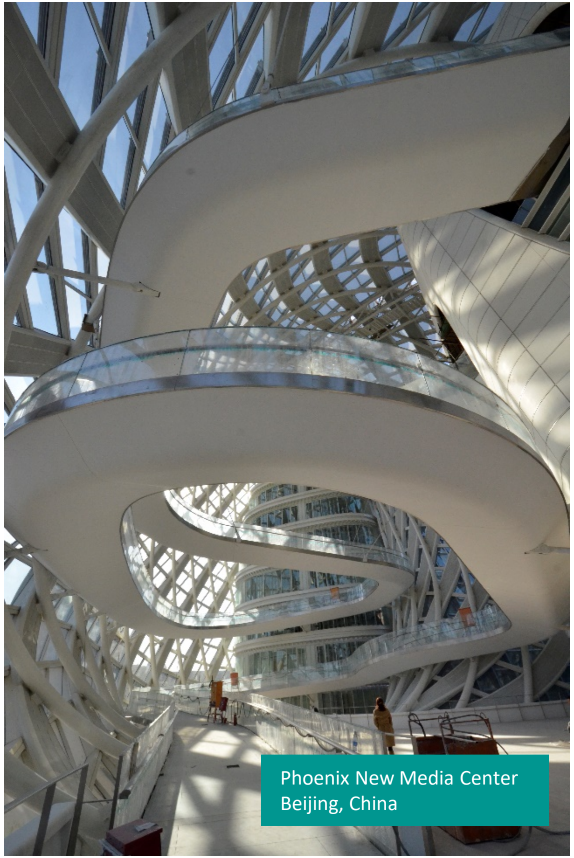
- Complexity in APPEARANCE
- Complexity in DESIGN REQUIREMENTS (Architectural, Engineering and Detailing)
- Complexity in FABRICATION
- Complexity in ERECTION

Queen Richmond Center
Toronto, Canada

The **Rise** in Complexity in Architecture

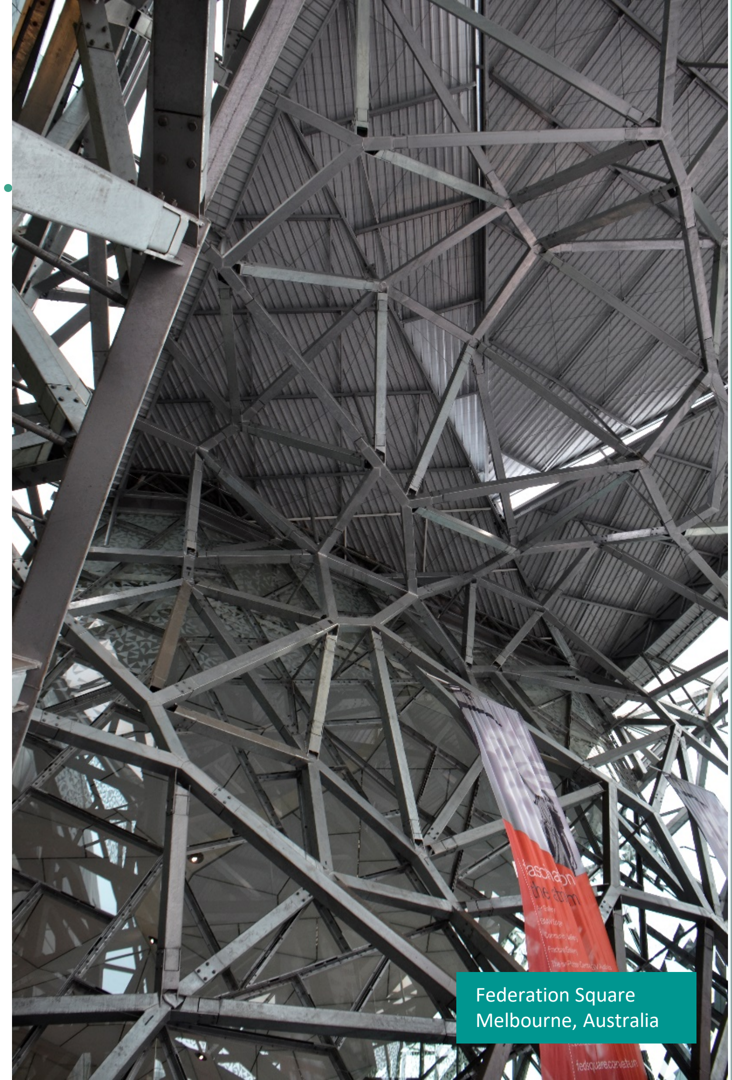
La Villette
Paris, France

- Starts with High Tech Architecture in the 1970s (modular + exposed steel)
- Pushed by Deconstructivist movement (irregular)
- Pushed by parametricism (curvature)
- Propelled by advances in computing


Phoenix New Media Center
Beijing, China

The **Cost** of Complexity

1. Base point is the choice between angular and curved geometries
2. Degree of irregularity in the (negating mass fabrication)
3. Exposed steel or concealed?
4. Using standard shapes or custom fabricated shapes



Federation Square
Melbourne, Australia

Complex Typologies

1. Mixture of Member Types
2. Three-dimensional Structural Types
3. Chaotic steel structures
4. Simple Curvature
5. Complex Curvature
6. Cast Connections
7. High Level of Custom Fabrication

Understanding the typology can help in determining the best methods for solving design issues arising from connections, fabrication and erection.

Obviously there is overlap between the types.

1. Mixture of Member Types

Convention Center
Sydney, Australia

- Most basic approach
- Arose from High-Tech style
- Highlights force differentiation in the member choice
- Often based on repeated elements
- Can take advantage of modular design and repetition
- *"Visual Complexity"*

1. Mixture of Member Types

- A shift from wide flange sections to tubular material and tensile reinforcing systems

Sainsbury Center England

- Early complexity of fabrication and detailing arose from introduction of tubular steel members

1. Mixture of Member Types

Pompidou Center
Paris, France

La Villette
Paris, France

- Changes from modular/regular to irregular geometry as we go from High-Tech to Deconstructivist

2. Three-dimensional Structural Types

- 3D geometry
- Cannot be solved as planar systems
- Often introduces irregularity
- Can include box or triangular trusses
- Includes diagrids and lattice/gridshell structures
- Often still a degree of repetition of details if not actual modularity

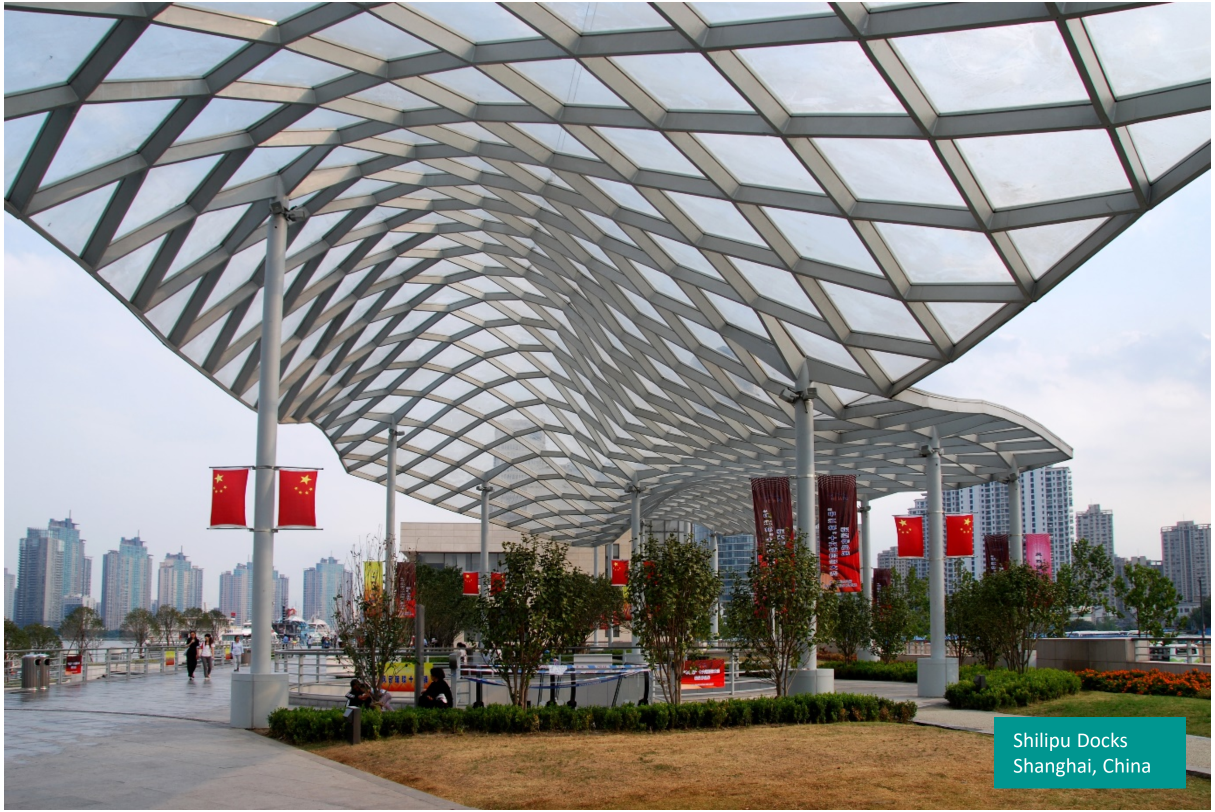
2. Three-dimensional Structural Types

- Often the members themselves might not be complex
- The arrangement challenges issues of balance for erectors
- Mixture of elements and members also creates visual complexity

Canadian Museum for Human Rights
Winnipeg, Canada

2. Three-dimensional Structural Types

- Lattice/gridshell structures present different fabrication issues
- Complexity of interface with glazing
- All welded requirements due to extensive use of node type connections



Shilipu Docks
Shanghai, China

3. Chaotic Steel Structures

- High degree of irregularity
- Virtually no repetition of connection design
- Deconstructivist style falls here
- Lack of simple modular design
- Often a variety of member type choices

3. Chaotic Steel Structures

- Much Deconstructivist work falls into this category
- Often no apparent order or repetition of details
- Erection challenges due to eccentric loads

Federation Square
Melbourne, Australia

3. Chaotic Steel Structures

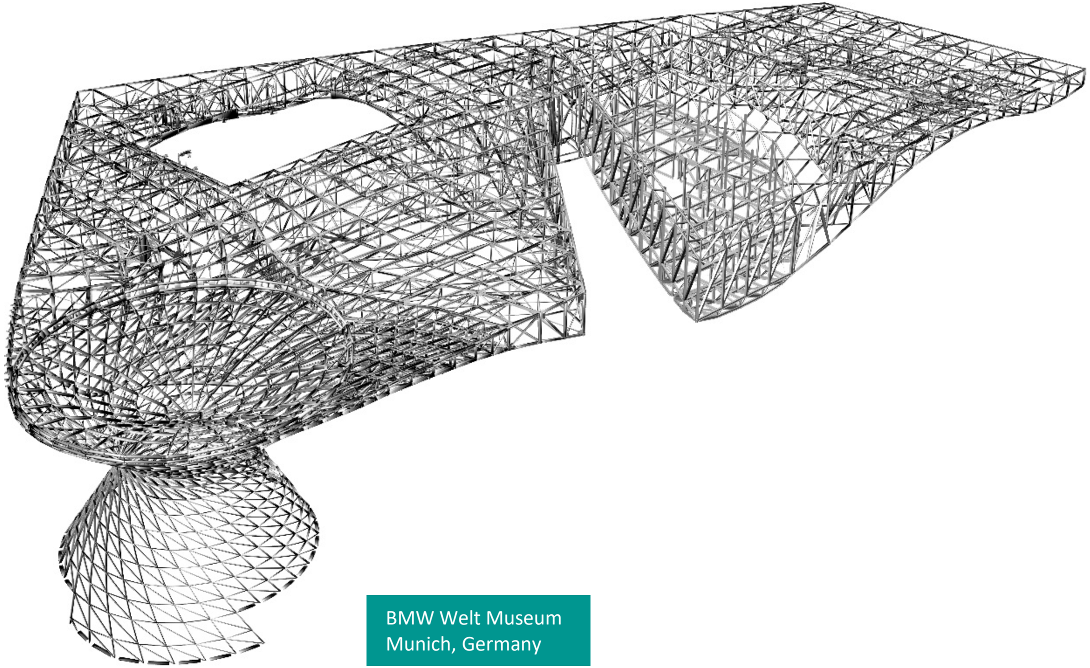


Image: Coop Himmelblau

BMW Welt Museum
Munich, Germany

- The use of 3D detailing software is critical to the construction of this work
- Truly not possible to construct prior
- Extensive shop drawing requirements given the uniqueness inherent in all structural elements

3. Chaotic Steel Structures

- Costs can escalate due to all welded, remediated connection requirements
- Extensive scaffolding needed for site welding

- Such systems also impact the design and fabrication of cladding systems and glazing

4. Simple Curvature

Porto Airport
Porto, Portugal

- Addition of simple curved elements (uniform curves)
- Added complexity to the project of the additional expertise of the roller/bender
- Splicing issues

4. Simple Curvature

- Bend the steel
  - Using a 3 point smooth bending machine
  - Using a brake press
  - Heat applied bending
- Cut curved forms out of plate material

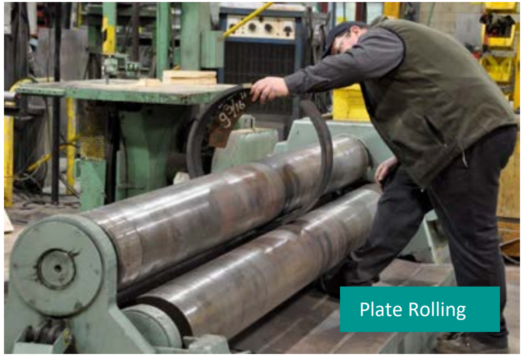
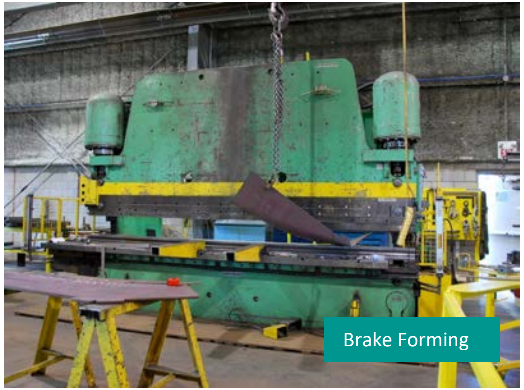


Plate Rolling


Brake Forming


Roller Bending

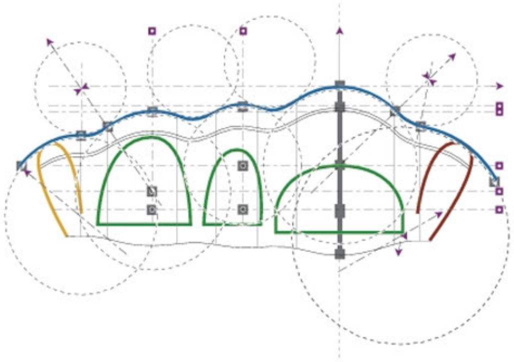
4. Simple Curvature


Chihuly Glass Museum
Seattle, WA


Wells Fargo Bank
Salt Lake City, UT

4. Simple Curvature

- As complicated as this project looks, it has been constructed from circular geometries



Sage Gateshead Theatre
Newcastle, UK

5. Complex Curvature

Southern Rail Station
Melbourne, Australia

- Often parametrically driven
- Need to accommodate connections between discontinuous curves
- Variation in connection design due to changing angles
- High level of customization

5. Complex Curvature

Arganzuela Footbridge
Madrid, Spain

- Although the overall forms are simple, the creation of custom hollow box sections required a high level of precision in rolling the plate steel

Puenta de Luz Footbridge
Toronto, Canada

5. Complex Curvature

- Non uniform curvature translates to the cladding
- Added engineering for non uniform configuration for loading

Image: Marc Fornes TheVeryMany

5. Complex Curvature

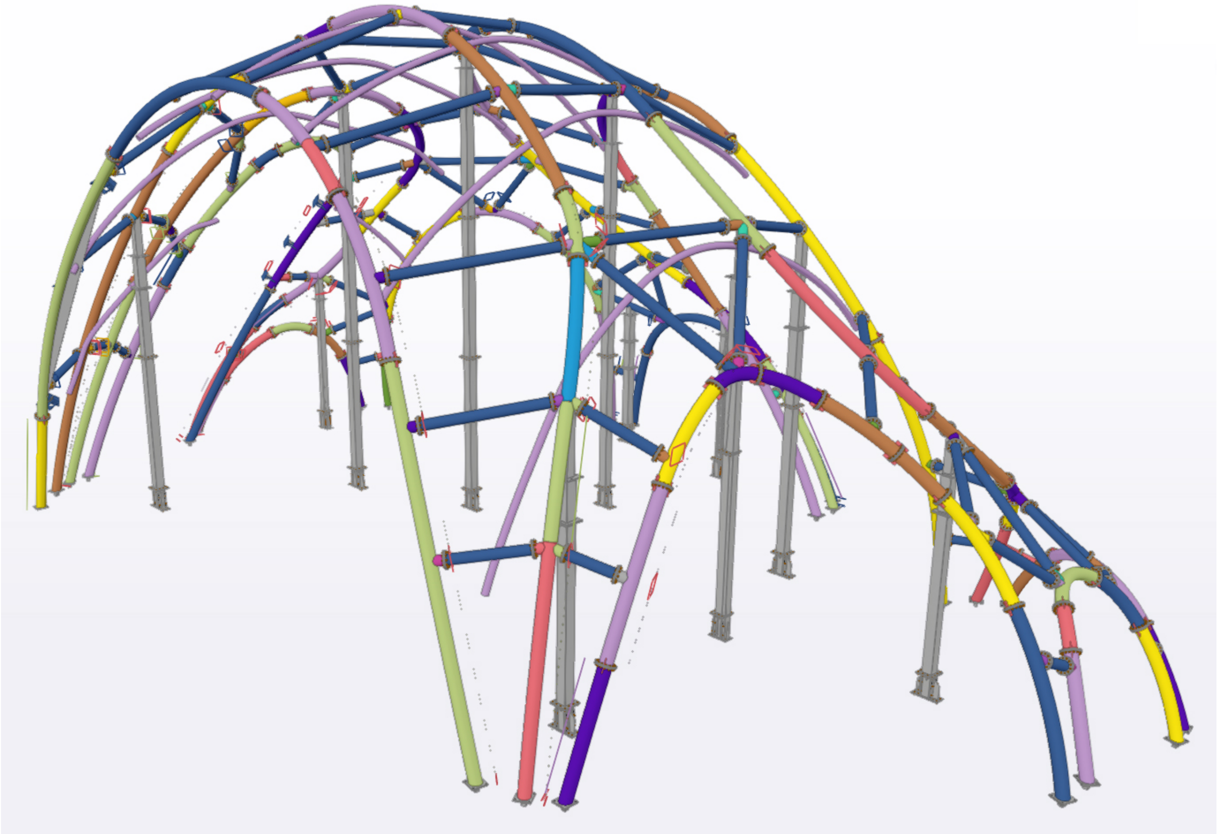


Image: Walters Inc.

- Advanced modeling essential to the success of the project
- Note extent of one-of members
- Careful coordination of elements for transport and erection
- Puzzle-like

5. Complex Curvature

- Erection logistics
- Need for temporary shoring as the structure is unstable until complete

- Uniform approach to connection design

Images: Walters Inc.

5. Complex Curvature

Phoenix New Media Center
Beijing, China

- Parametrically driven curved geometries
- High level of AESS
- Seamless splices required on tubular materials
- Hidden integration of MEP into structural framework

6. Cast Connections

Queen Richmond Center
Toronto, Canada

- Perhaps simpler in "appearance" but more complex in terms of engineering requirements
- Different erection and fabrication concerns
- Good way to solve complex geometries at points of member convergence

6. Cast Connections

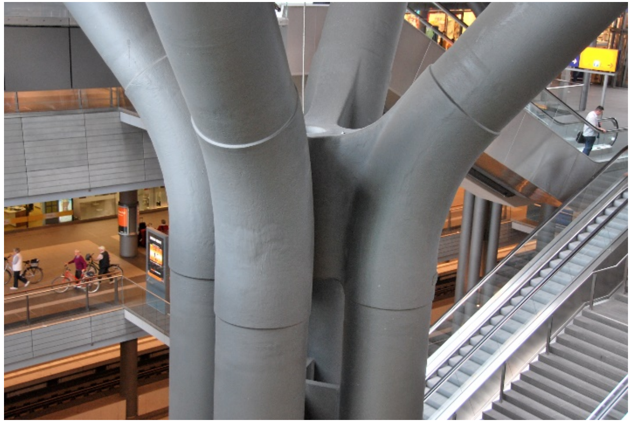


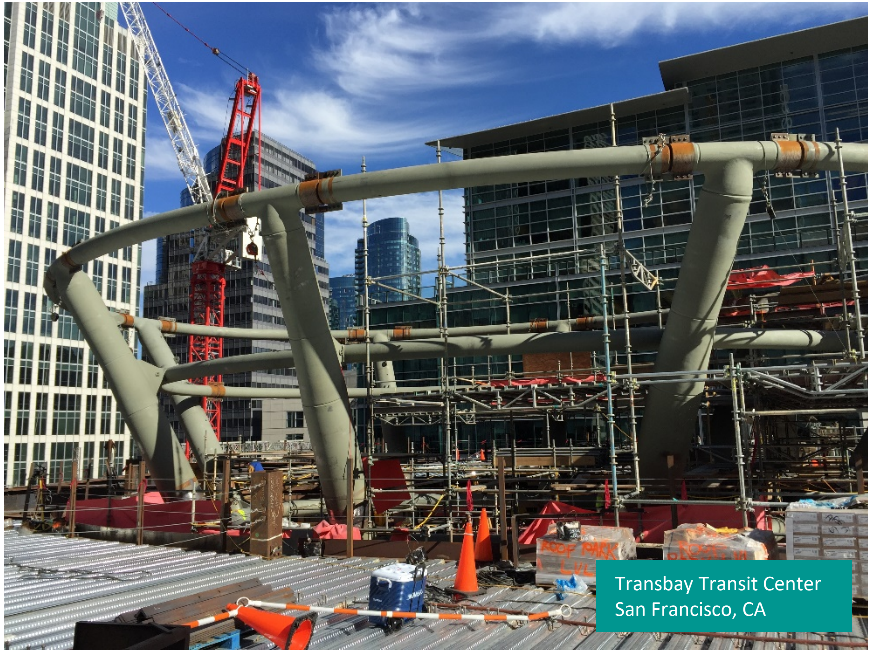
Image: CastConnex

- Size varies
- Can be for end conditions or major nodal points
- Hollow or solid as a function of loading

6. Cast Connections

- Essential to retain specialized engineering consultant to the project
- Oversees the casting

- Unique detailing due to the different surface condition of the casting



Transbay Transit Center
San Francisco, CA

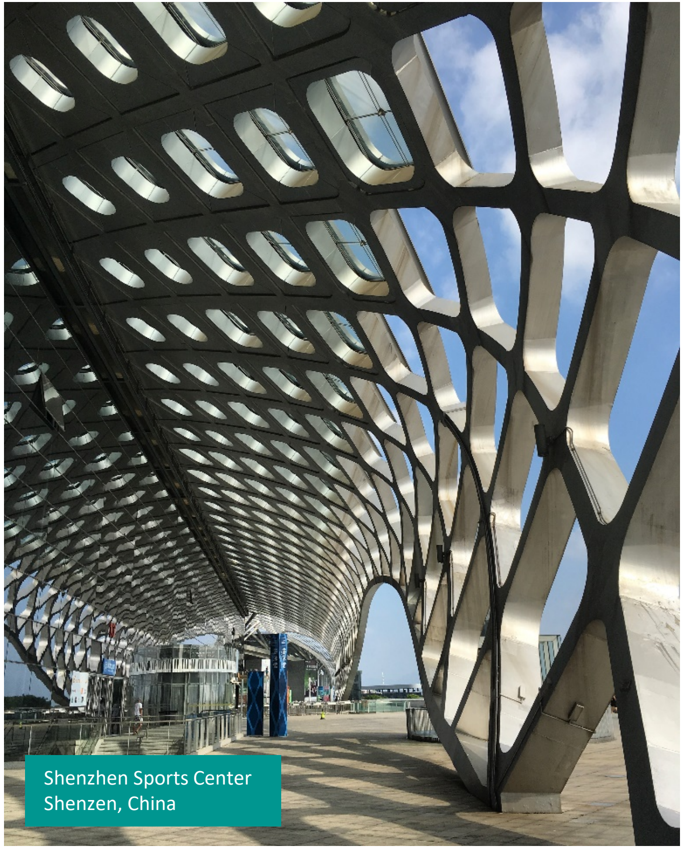
7. High Level of Custom Fabrication

Peace Bridge
Calgary, Canada

- Marked shift to custom fabricated elements from plate steel
- High level of weld remediation
- Typically AESS 4 type category
- Use of plate rolling and brake forming
- Irregular curves and angular geometry

7. High Level of Custom Fabrication

- Often used in conjunction with complex curvature
- Greatly impacts the cost of construction

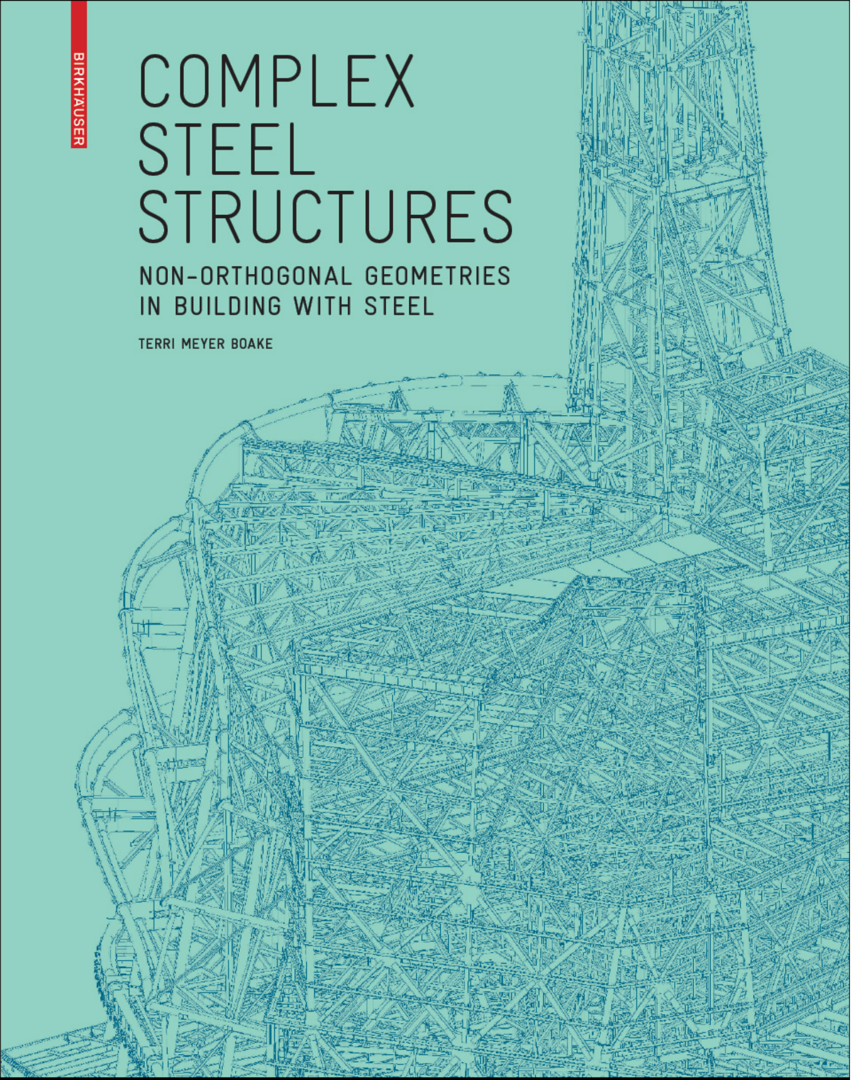


Shenzhen Sports Center
Shenzen, China

7. High Level of Custom Fabrication

- Extensive plate cutting to create the widely varied nodes
- Entirely non orthogonal geometry

The Shed
New York City, NY



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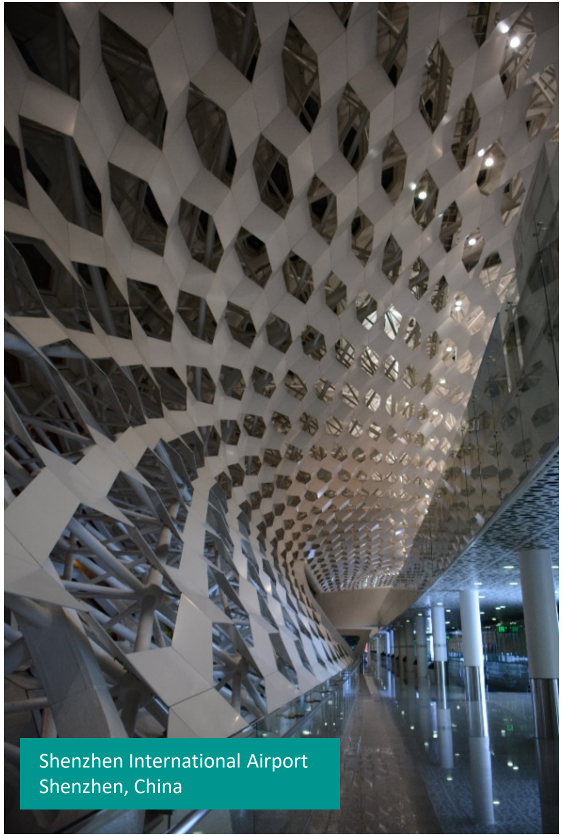
ARCHITECTURE IN STEEL

Economically Driven Strategies:



Shenzhen International Airport
Shenzhen, China

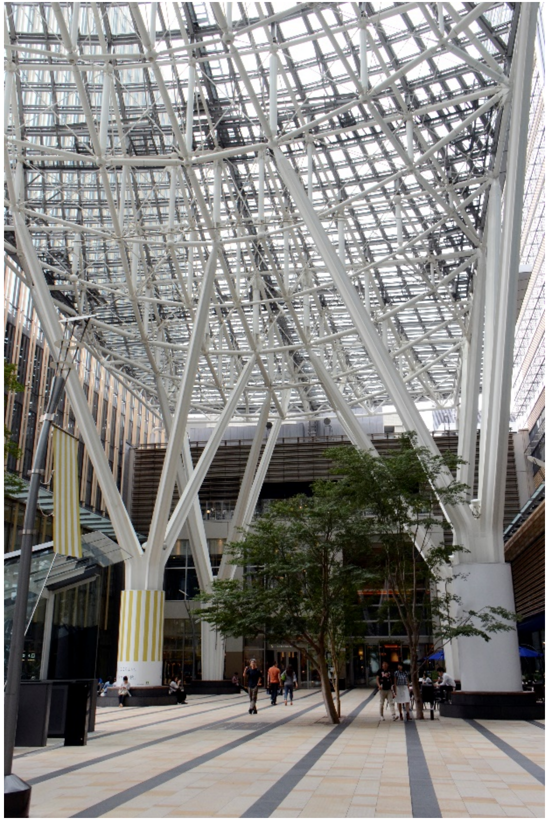
1. The Distance Factor
2. Faking the Curve
3. Semi-exposure and the Use of Screen Elements
4. Making the Steel Recede

1. The Distance Factor

- Follows the same logic as AESS Category System
- Detailing can be softened the further from the view distance
- Implies higher level of fabrication up close and rougher detailing far away
- A layering of systems

Tokyo Midtown
Tokyo, Japan

Tokyo Midtown, Tokyo, Japan

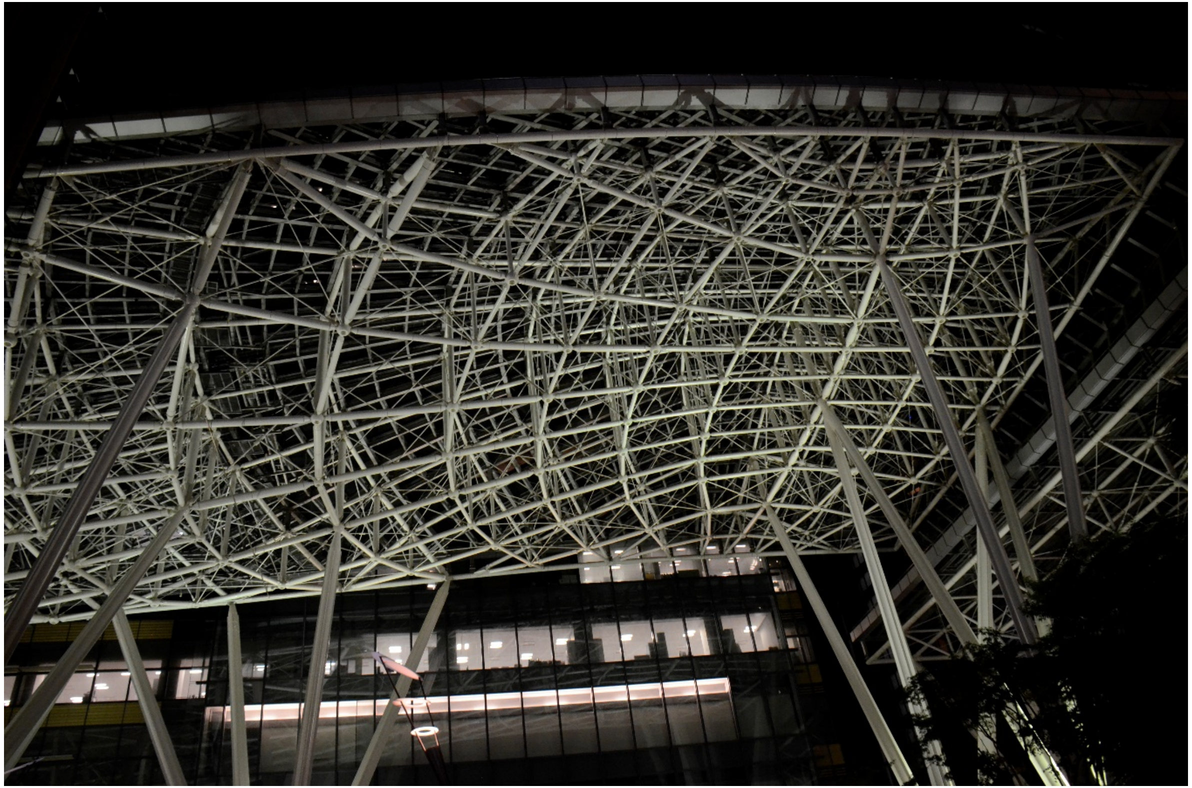


- More refined AESS detailing with full welding for the columns
- Selective weld remediation with fillet welds where the plate meets the tube left in, but splice welds remediated

Tokyo Midtown, Tokyo, Japan

- Welded connections between columns and white trusses unremediated
- Simpler members and bolted splice connections
- Highest level changes colour to visually recede and uses wide flanges

Tokyo Midtown, Tokyo, Japan



- The high level truss structure also uses straight segments to create the illusion of a curved structure
- Details more obvious with the night lighting

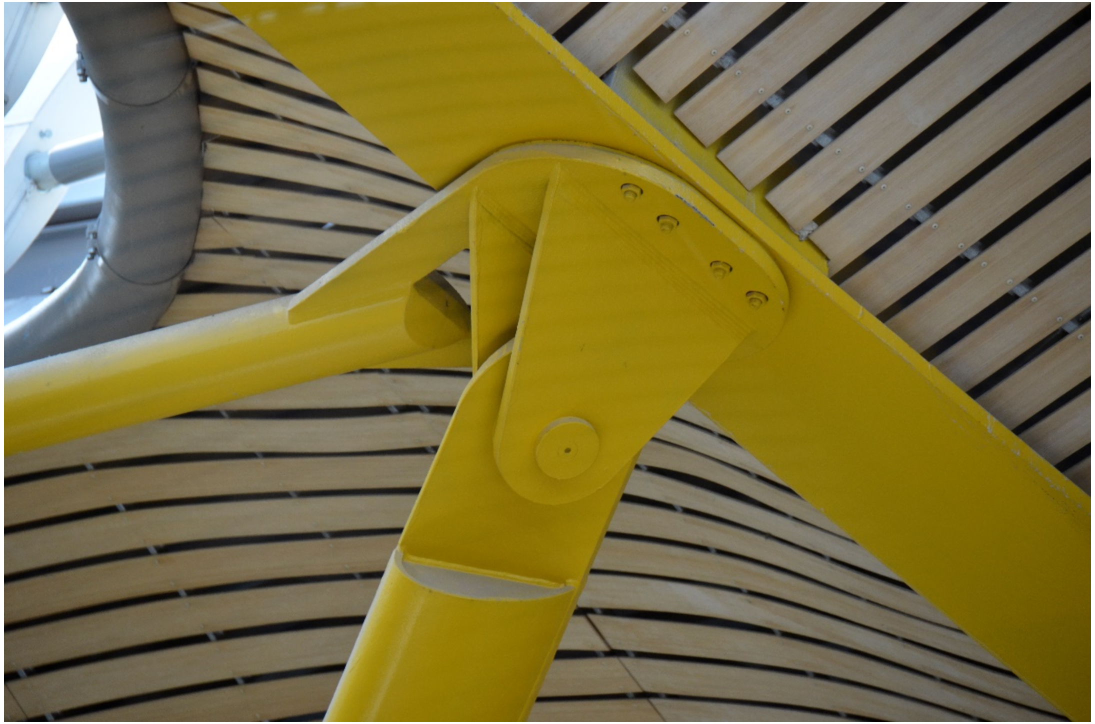
Barajas Airport, Madrid, Spain

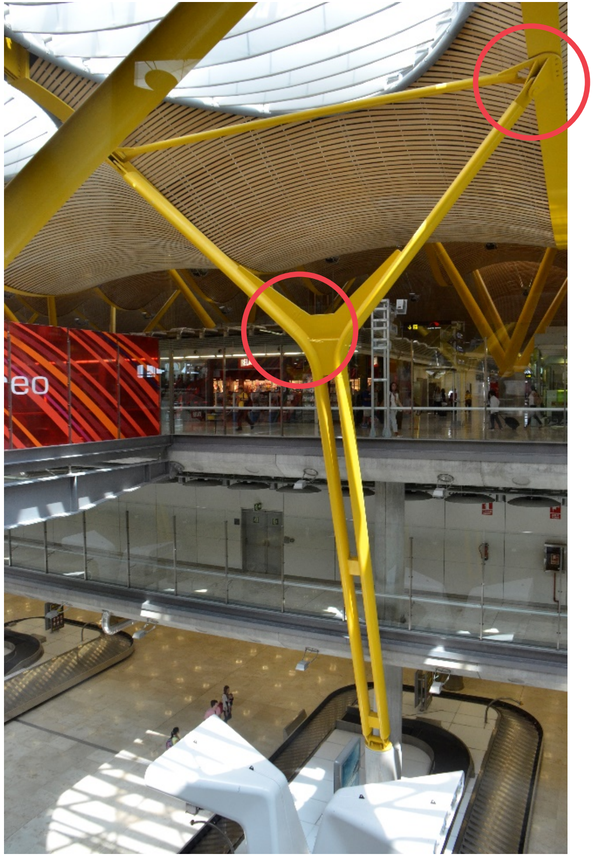
- The distance factor allows for a softening of the details at the high ceiling level
- Only the bottom edge of the curved support beam is finished to AESS 2 type quality as the upper portion is concealed.

Barajas Airport, Madrid, Spain

- The lighting and the choice of color have allowed for zero weld remediation on the splices between the segments of the tapered tubes
- The distance factor helps here
- The multiplication factor helped to justify the decision

Barajas Airport, Madrid, Spain





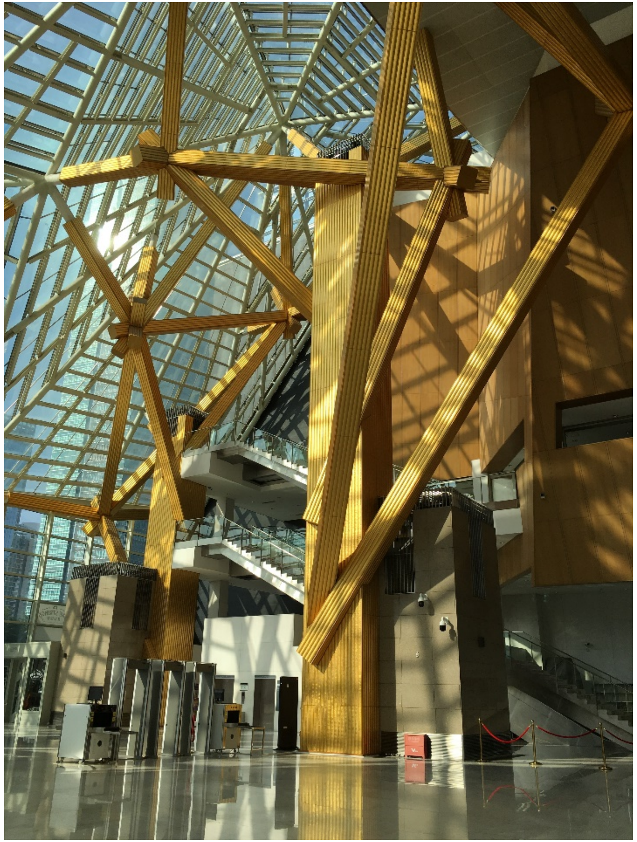
Barajas Airport, Madrid, Spain

- The extreme height of the Y supports necessitate site welding for the splice
- You can see that the temporary tabs have been removed and their evidence not ground away
- Distance factor allows for little remediation

Shenzhen Cultural Center, Shenzhen, China

- A highly angular structural geometry
- Large atrium spaces at the entrances with distant views

Shenzhen Cultural Center, Shenzhen, China



- High end use decided to clad the steel at the base of the structure obviating any need for fine steel detailing
- Skylight steel exposed but at a very distant view

Shenzhen Cultural Center, Shenzhen, China

- Details located at height are fairly crude, but not seen

2. Faking the Curve

- True curved steel adds to the cost of the contract – specialty fabrication
- Consider that it is the APPEARANCE of curvature that is desired
- The SCALE of the project or element can allow the use of all straight segments
- Simpler fabrication and erection but high cost savings

Waterfront Theater
Boston, MA

Simplification through Straight Segments

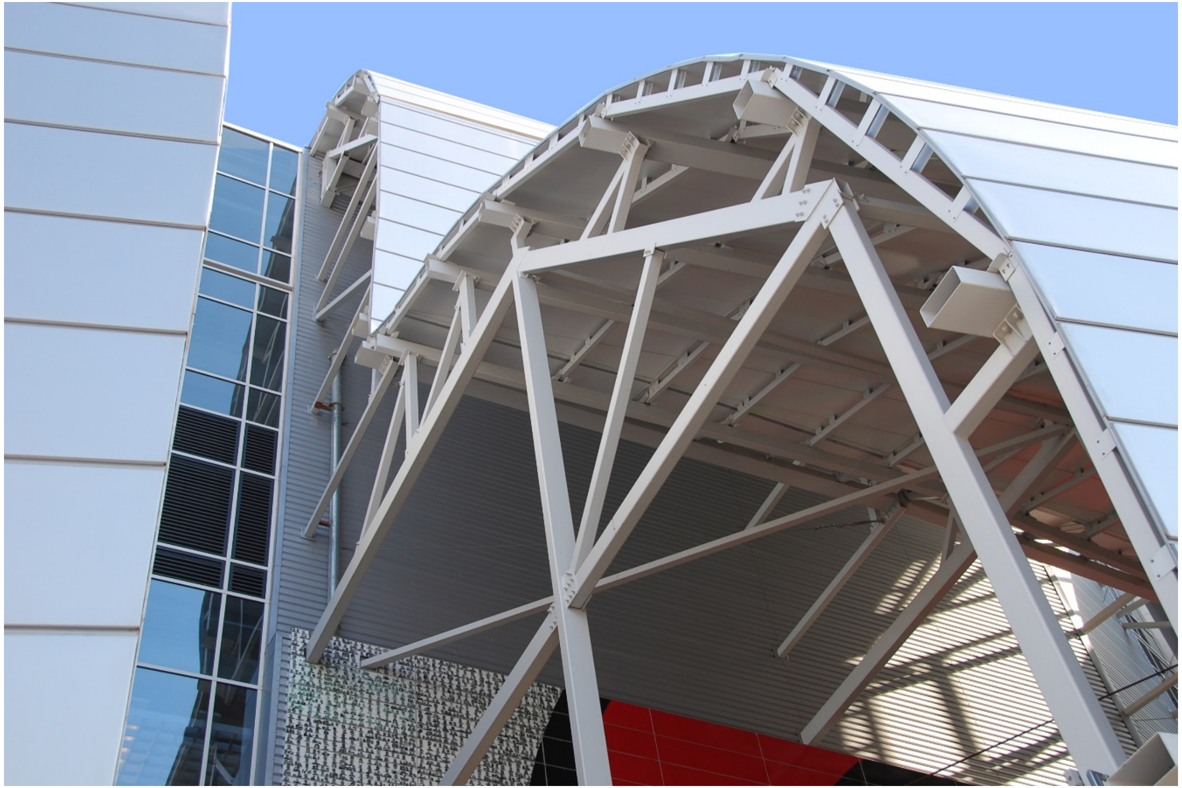
- Overall scale plus viewing distance
- Use of all straight segments to create a faceted curve
- Distance to view allows for very simple bolted end connections

University of Phoenix Stadium, Phoenix, AZ

- Extremely large scale of building
- Exterior looks curved but is fabricated from all straight segments
- Able to make use of repetitive geometry
- Cladding also uses flat panels

University of Phoenix Stadium

- The curvature is built out
- Starts with very straight segments
- As the structure approaches the skin the facets become finer
- Organized to allow for horizontal cladding



Diamond Lantern, Beijing, China

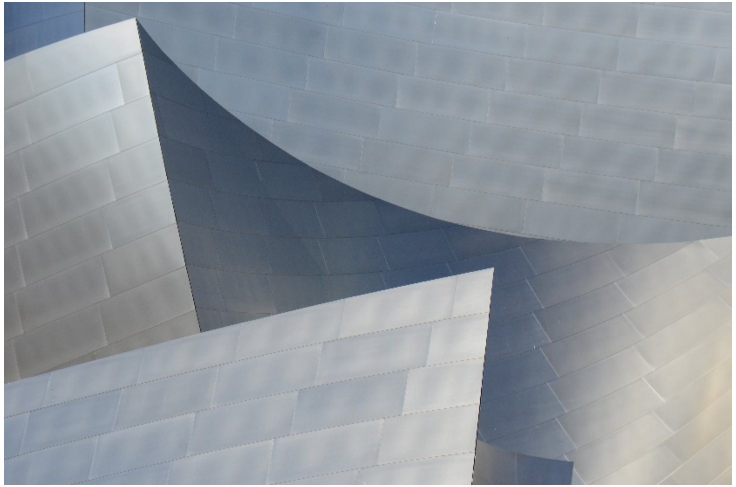
- Elliptical plan
- Tower fabricated from all straight concrete filled tubes
- Nodes fabricated to make the curved transition
- Intended to look like a paper lantern so facets agree with the aesthetic idea

Diamond Lantern, Beijing, China

- Faceted design creates economy in the façade
- Allows for the use of flat insulated glass panels
- Modular design for the curtain wall

Disney Concert Hall, Los Angeles, CA

- Much of the steel that comprises the work of Gehry is straight
- The curvature is achieved only at the level of the façade itself



Jay Pritzker Pavilion, Chicago, IL

- By separating the requirements of the structure from the cladding the fabrication can be simplified

- The aesthetic sought a rougher looking suite of bolted connections

3. Semi-exposure and the Use of Screen Elements

- Similar to "faking the curve" recognizes a separation of the aesthetic of the façade and the structure
- A partial view to the structure is allowed, meaning softening of the detailing requirements
- Creates a distance to view condition


Cooper Union
New York City, NY

Different Kinds of Materials can be Screens


Barajas Airport
Madrid, Spain


The Watercube
Beijing, China

- Various materials can be used in front of the steel to obscure the view
- Allows for a softening of the detailing
- Slats, ETFE, glass, perforated metal


Federation Square
Melbourne, Australia

Shenzhen Bao Airport, Shenzhen, China

- Fairly standard space frame is used
- A bent, lightweight metal screen allows a partial view through to the structure
- Extensive skylights above
- Space frame and screen provide shading during the day

Shenzhen Bao Airport, Shenzhen, China

- Screen elements must be light enough to avoid loading the structure
- The bent shape provides rigidity
- Also serves to obscure mechanical services

Shenzhen Bao Airport, Shenzhen, China

- The project also makes use of faceting versus true curvature in both the space frame and the screen

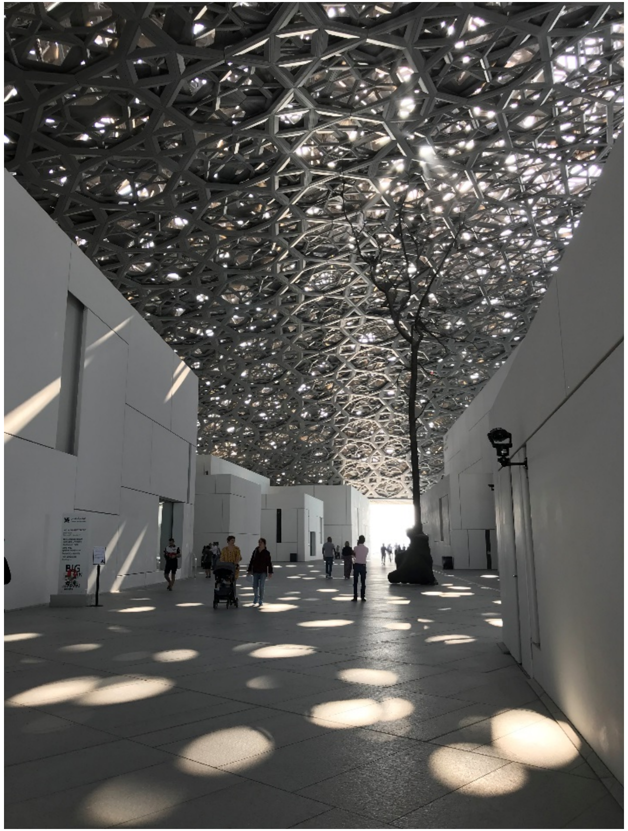
Beijing Capital Airport, Beijing, China

- Use of a slatted screen beneath the spaceframe structure
- Allows for light to penetrate from the skylights above
- Provides spatial definition while still letting you feel the presence of the structure

Beijing Capital Airport, Beijing, China

- Continuity of appearance from interior to exterior
- Slats are panelized to allow for removal for maintenance
- Hide mechanical systems
- Project also has large scale curvature that uses a faked curve

The Louvre, Abu Dhabi, UAE



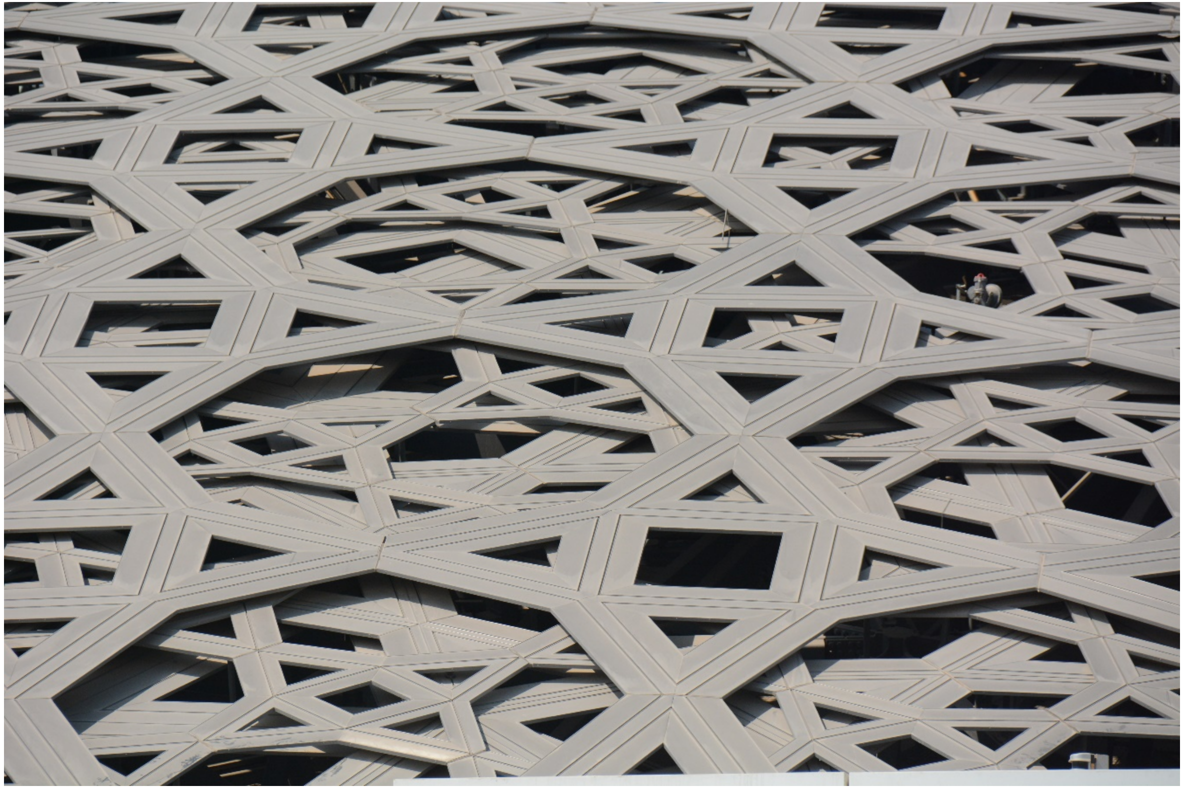
- Large multi-layered screen serves as a mashrabiya type sun shade

The Louvre, Abu Dhabi, UAE

- The space truss is around 5m deep
- Different screen elements on the exterior and exterior based on type of materials and level of perforation

The Louvre, Abu Dhabi, UAE

- Exterior view of the stainless steel screen elements
- Overlapping style creates more difficult paths for the sun to penetrate
- Very hot humid climate



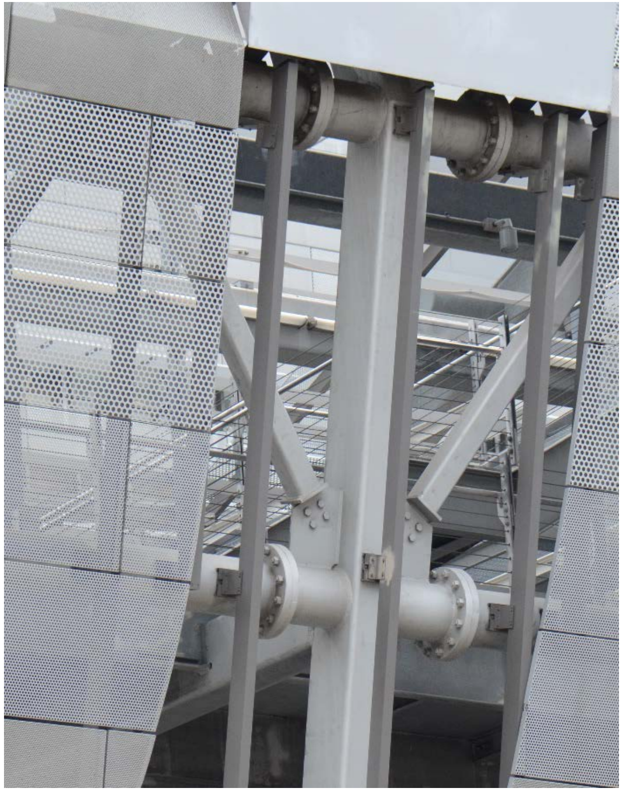
The Louvre, Abu Dhabi, UAE

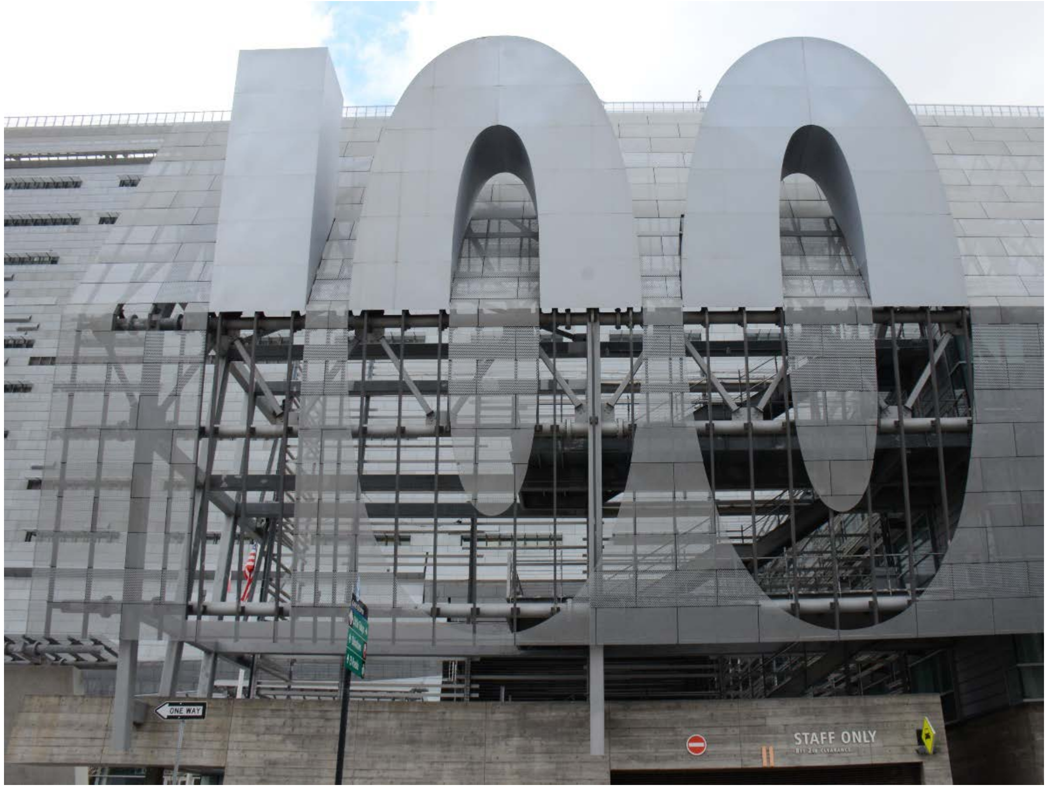
- Scant view from the interior through the screen to the structure
- Quite simple detailing of the connections
- Use of HSS shapes to preclude places for water/sand to build up (this is open air)

Caltrans HQ, Los Angeles, CA

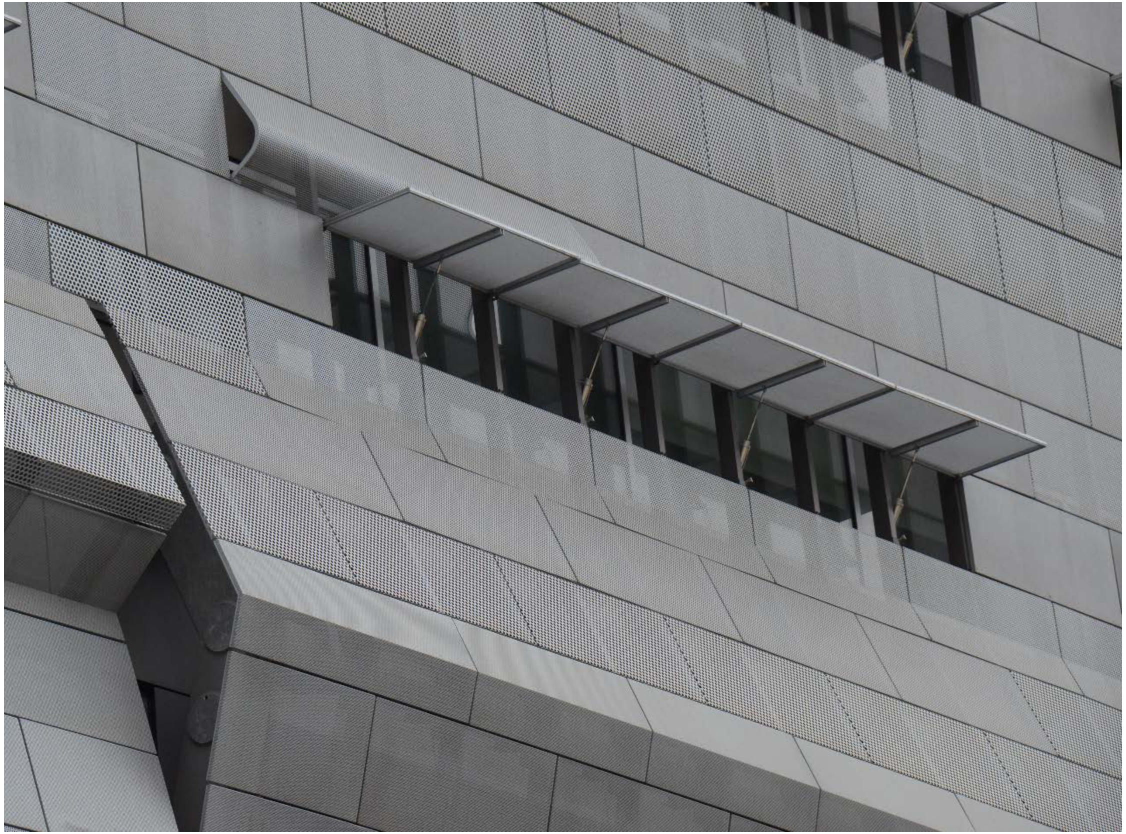
- Deconstructivist style
- Use of perforated screens that allow partial or obscured views to the structure
- Consistent use of color to blend the two together

Caltrans HQ, Los Angeles, CA





Caltrans HQ, Los Angeles, CA



San Francisco Federal Building, San Francisco, CA

- Perforated stainless steel screens that take on an angular, edgy look cover a very rectangular concrete office tower
- Galvanized steel frame supports and provides the form

San Francisco Federal Building, San Francisco, CA

- Placing the exposed highly angular, specialized elements at grade and close to view provides the overall angular feel of the project
- Allows the detailing up high to be more simple
- Base provides the first impression

San Francisco Federal Building, San Francisco, CA

- Bolted splice connections between the shop fabricated larger elements
- Mix of member types to add to the eccentricity of the project
- Galvanized coating for durable exterior location

4. Making the Steel Recede

- Adjacency maybe used to shift the focus away from exposed supporting steel, thereby allowing to soften its fabrication detailing.
- The eye of the viewer will be drawn to a more finely detailed and polished part of a project
- The structural support system, though clearly visible, takes a visual back seat.
- The steel may also be completely clad, but still very perceptible as being a steel structure

Jewish Museum Courtyard, Berlin, Germany

- By the form, we know this to be steel
- Cladding permitted softening of the detailing
- The cladding system was used to provide
  - Aesthetics
  - Fire protection
  - Route for MEP

Jewish Museum Courtyard
Berlin, Germany

Royal Ontario Museum, Toronto, Canada

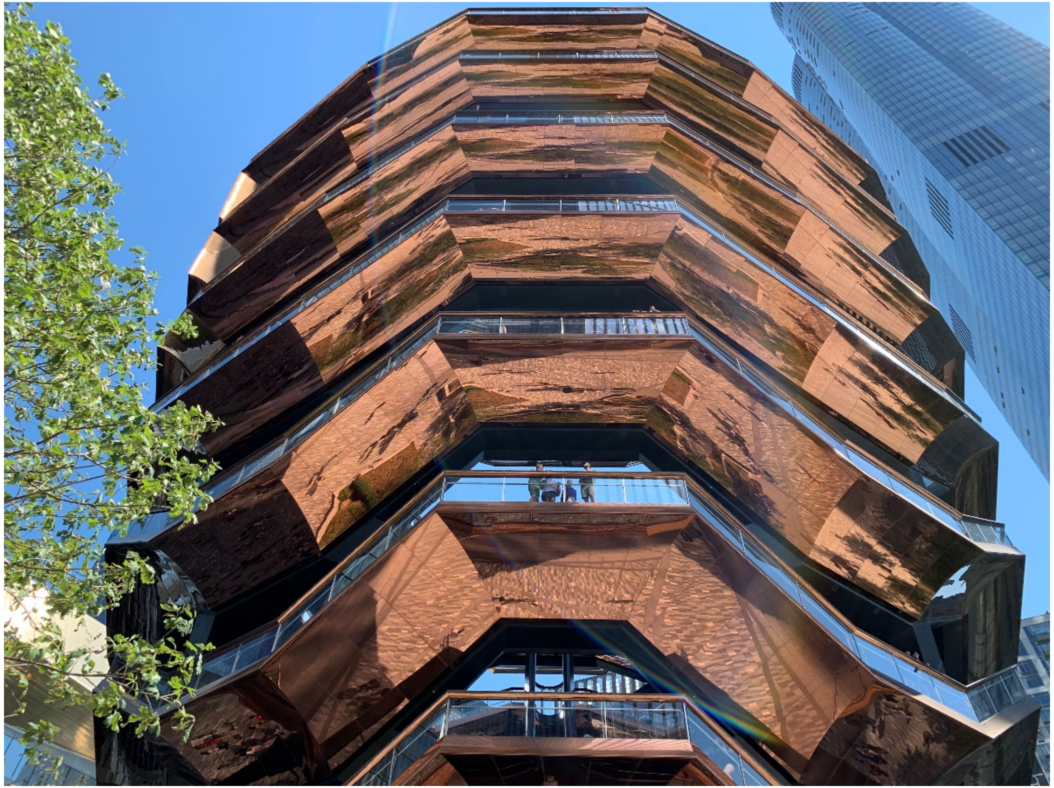
- Diagrid type structures are typically constructed of steel
- Often clad for fire protection

- The structure does not need to be completely exposed for the steel to be appreciated or "felt"

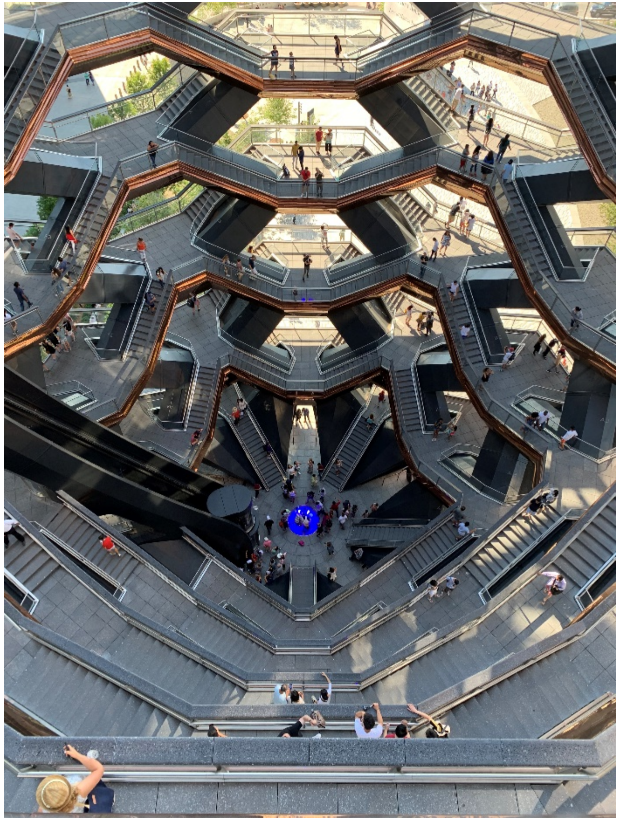
Royal Ontario Museum
Toronto, Canada

The Vessel, New York City

- Large, prefabricated steel elements were essential to providing a self supporting central steel structure for this feature attraction
- The shiny copper colored cladding on the exterior takes main stage, making the steel support system recede from view



The Vessel, New York City



The Vessel, New York City

- Hidden bolted connections were used on site to facilitate an easier erection
- Modules were prefabricated in Italy and shipped by barge to the site

Lou Ruvo Brain Institute, Las Vegas, NV

- The formal exterior face is clad in stainless steel
- Exposed steel constitutes the back face, receding from view on the building exterior
- Detailing is rugged as per the Deconstructivist style of Frank Gehry

Lou Ruvo Brain Institute, Las Vegas, NV

- There is a marked aesthetic contrast between the exterior view and the courtyard

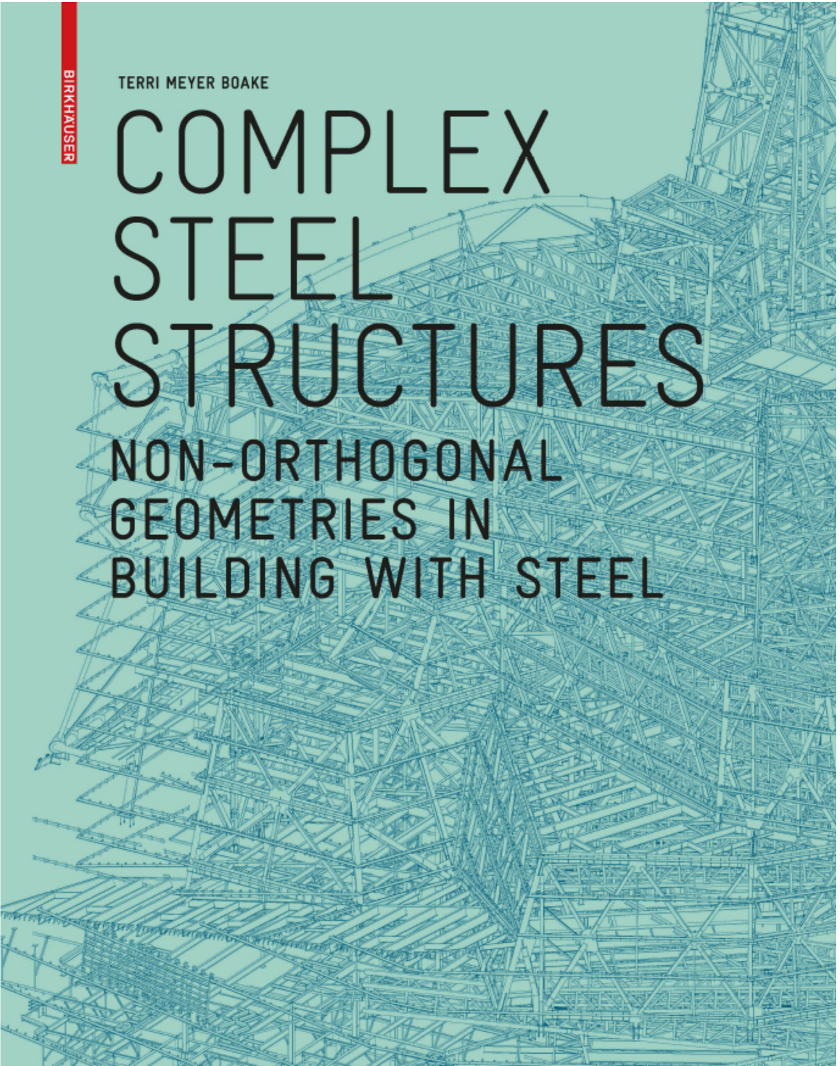
- The steel elements are largely shop fabricated for welded connections
- Bolted connections on site

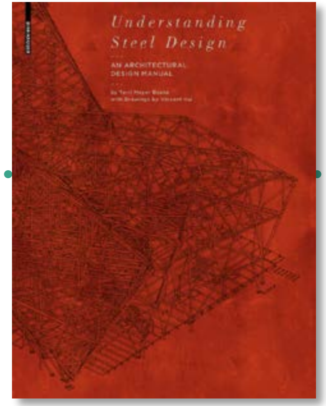
Lou Ruvo Brain Institute, Las Vegas, NV

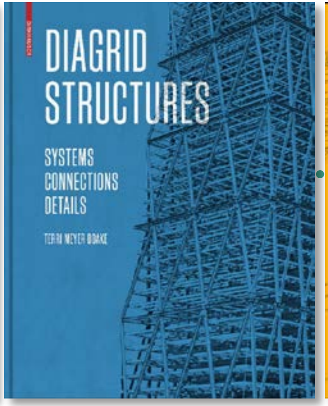
- The steel structure is completely clad in gypsum board on the interior for the function space
- The steel still has an aesthetic presence
- Also even a coherence in spite of being fully exposed on the exterior and clad on the interior

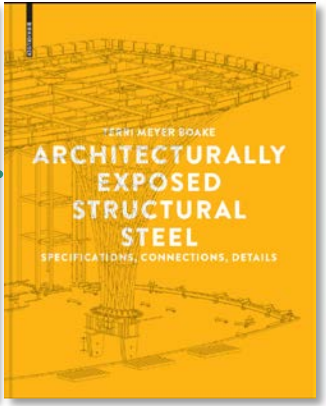
Take Aways

- Complex steel structures require a higher than normal level of communication between the architect, engineer and fabricator
- Deciding on the AESS Category, level of exposure and type of complexity will assist in simplifying decision making
- Understand that complexity is visually driven
- There are choices in methodology that can allow for some increased economy for the project









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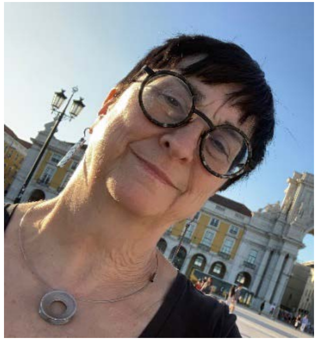

NASCC: THE VIRTUAL STEEL CONFERENCE

ARCHITECTURE IN STEEL