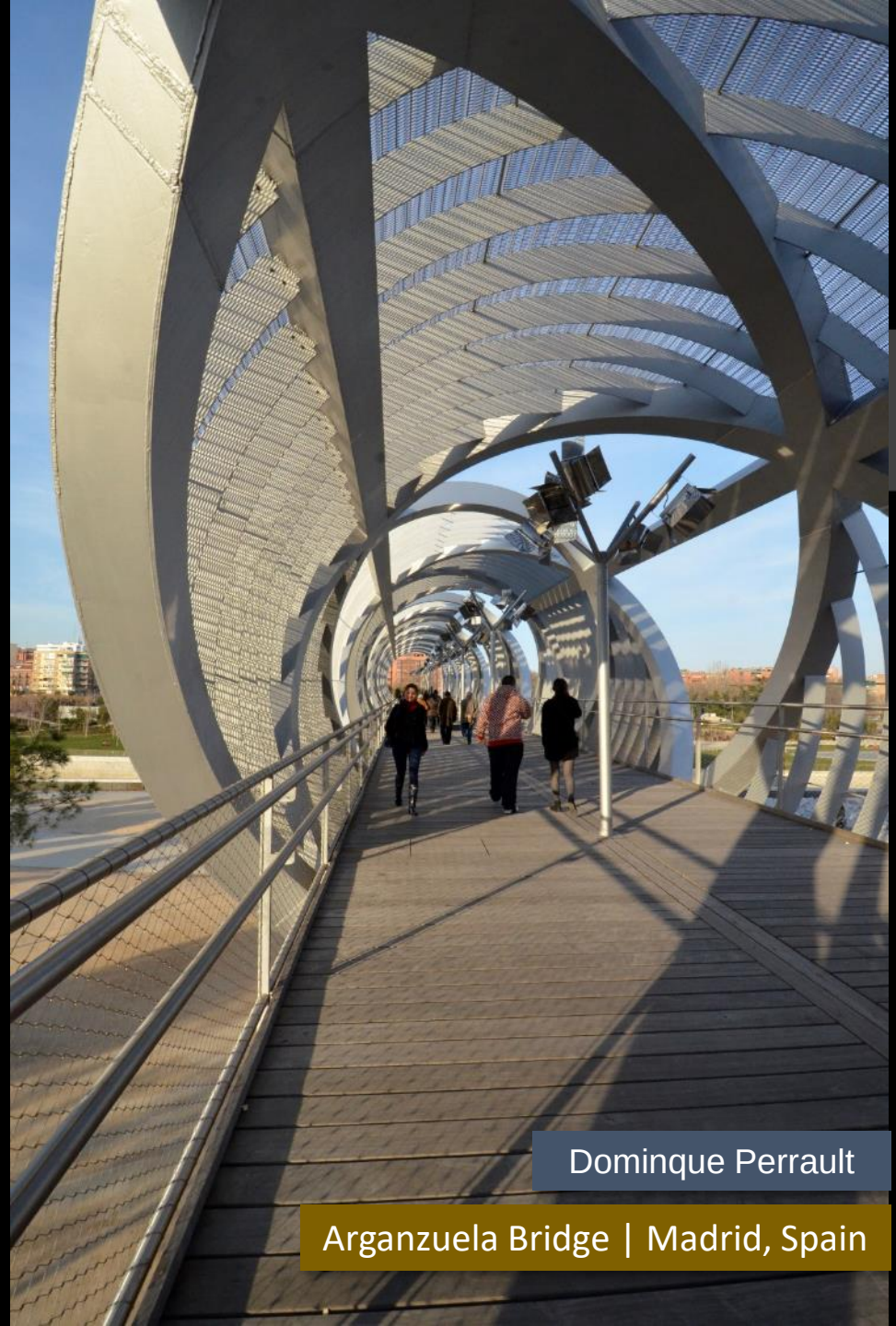


STEEL

CURVED STEEL

Terri Meyer Boake
BES Barch MArch LEED AP

School of Architecture
University of Waterloo, Canada

3 Ways of Tackling “Curves”

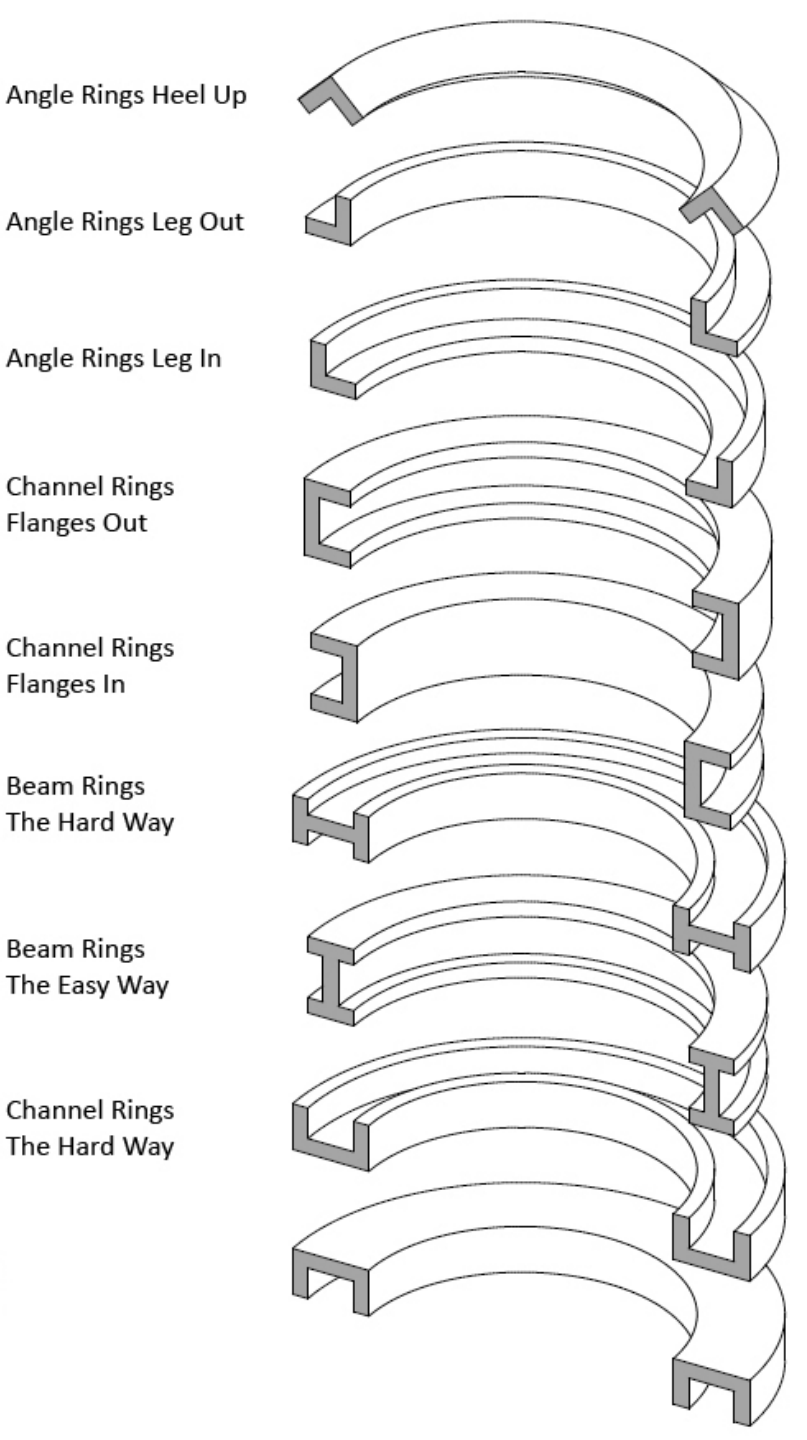
- Bend the steel
  - Using a 3 point smooth bending machine
  - Using a brake press
  - Heat applied bending
- Facet the building to give the appearance of curves while using straight members
- Cut curved forms out of plate material

Bending Steel Issues

- Member type
- Orientation of member
- Length of member
- Shipping considerations
- Sourced out work
- Accuracy of curve
- Multiple curves

Hard Way vs. Easy Way?

- Different shapes are more or less “easy” to bend
- Tendency for buckling on tighter curves
- Thin steel likely to buckle
- Heavier steel harder to bend



Induction bending

This sort of specific heat application process is used more for industrial pipe rather than architectural applications.

Red Hill Parkway Bridge, Hamilton

Induction bending done due to the sheer size of the members.

Three Point Pressure Method

Correctness of curve


ROUNDO

Wells Fargo Pedestrian Bridge | Salt Lake City, Utah


Foster + Partners
Sage Theater | Gateshead, UK

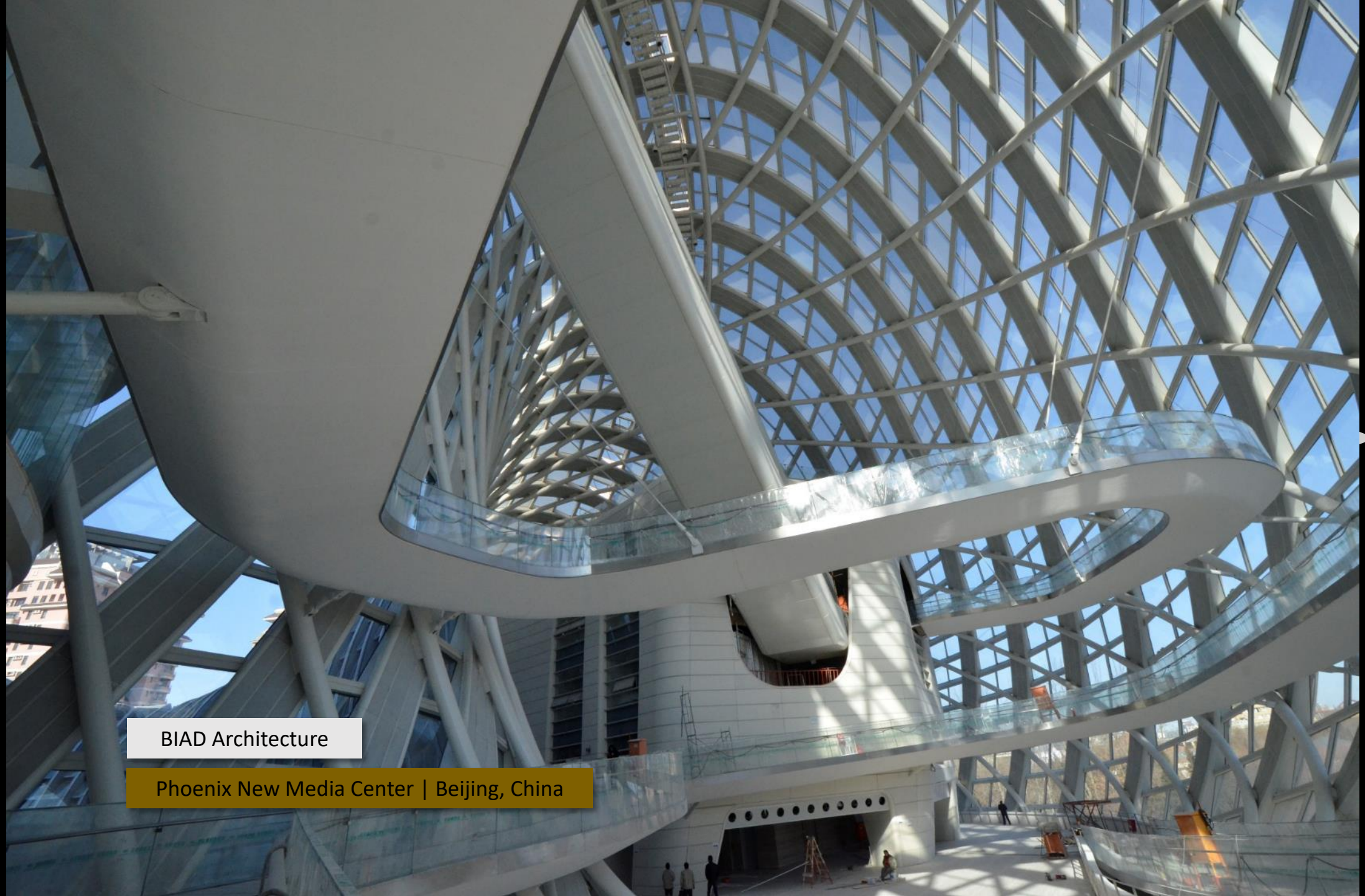

Nicholas Grimshaw
Railway Station | Melbourne, Australia

John McAslan + Partners

Kings Cross Station | London, England

Sculptural Stair

Munich, Germany


BIAD Architecture
Phoenix New Media Center | Beijing, China

http://www.archdaily.com/165746/in-progress-phoenix-international-media-center-biad-ufo/

http://www.archdaily.com/165746/in-progress-phoenix-international-media-center-biad-ufo/

http://www.archdaily.com/165746/in-progress-phoenix-international-media-center-biad-ufo/

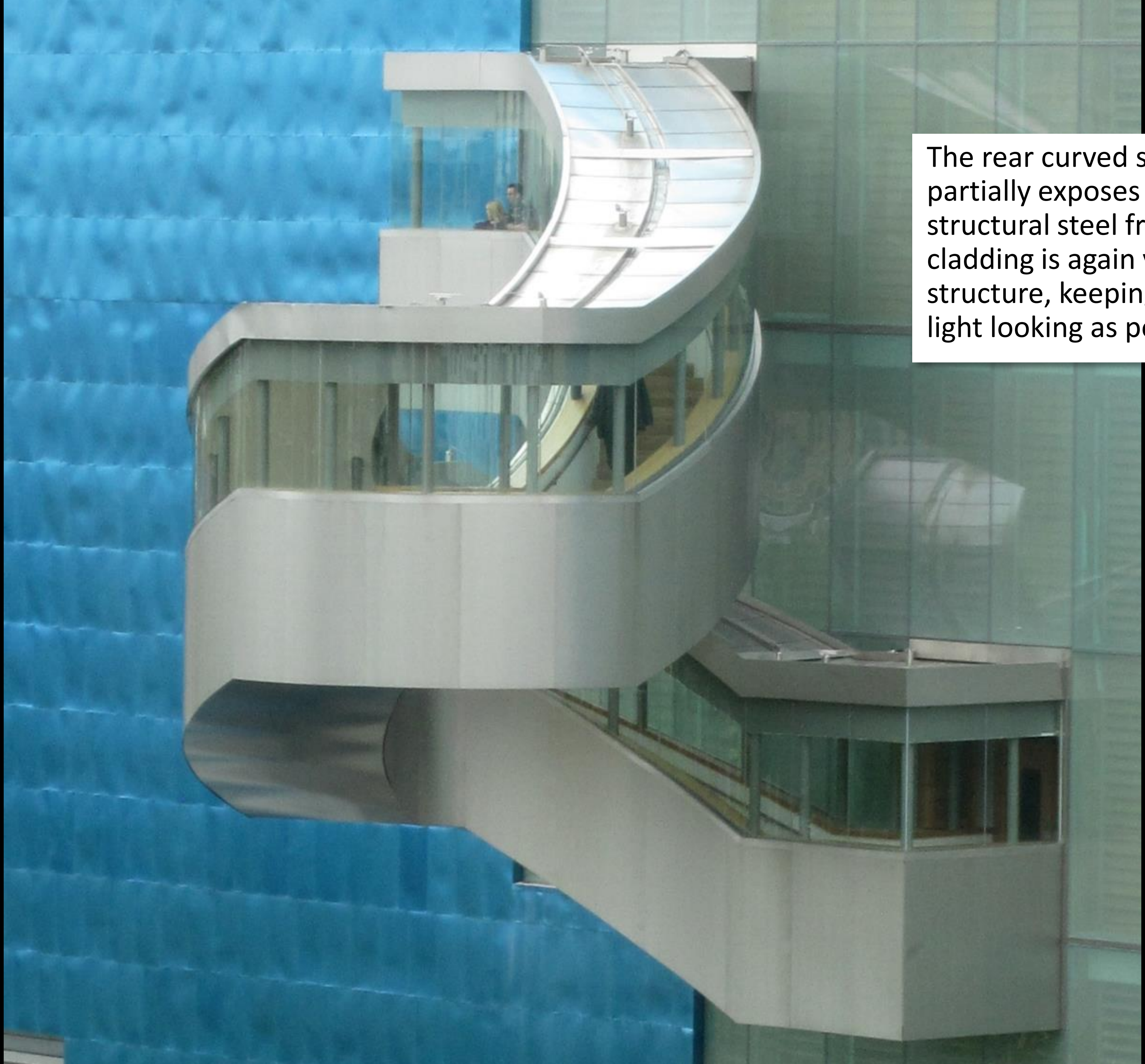
Frank Gehry

Art Gallery of Ontario, Toronto

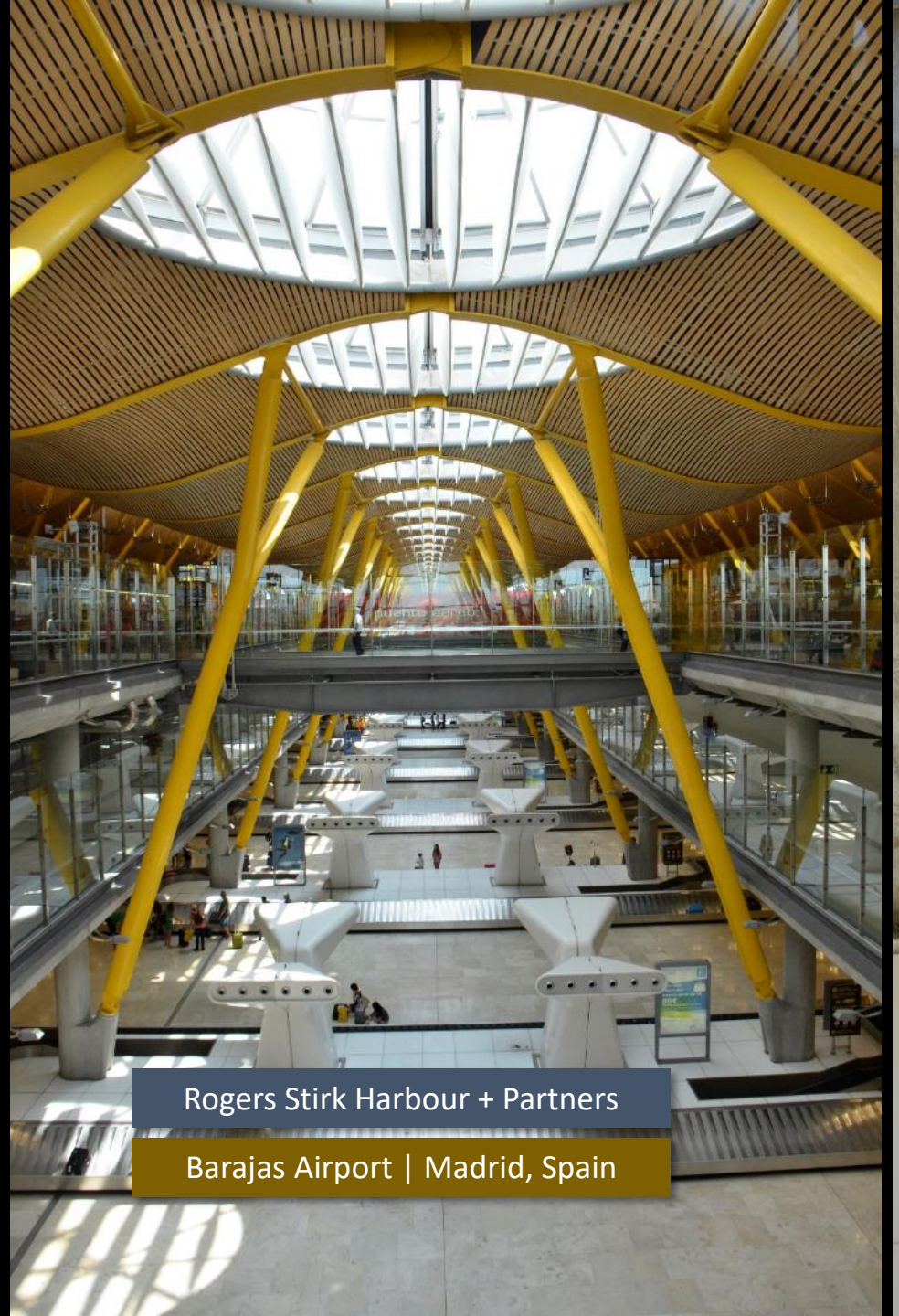
The curved stairs on the Art Gallery of Ontario were fabricated using round HSS. There were difficulties in ascertaining approval of the splices as unavoidable deformations happen when bending tubes, so guarantees on the welds were difficult.

When splicing tubular steel so that the joins are not evident, it is typical to use an inset sleeve to form the backstop for the weld. Given the angular splice and deformation of the material, this proved to add a challenge to the splice.

Although workmanship was not a large issue in making the splices, the contractor could not use plates or bulkier methods as the cladding for the stair was to be very tight to the steel.



The rear curved stair of the AGO partially exposes the tubular structural steel frame. The cladding is again very tight to the structure, keeping the stair as light looking as possible.



Rogers Stirk Harbour + Partners

Barajas Airport | Madrid, Spain

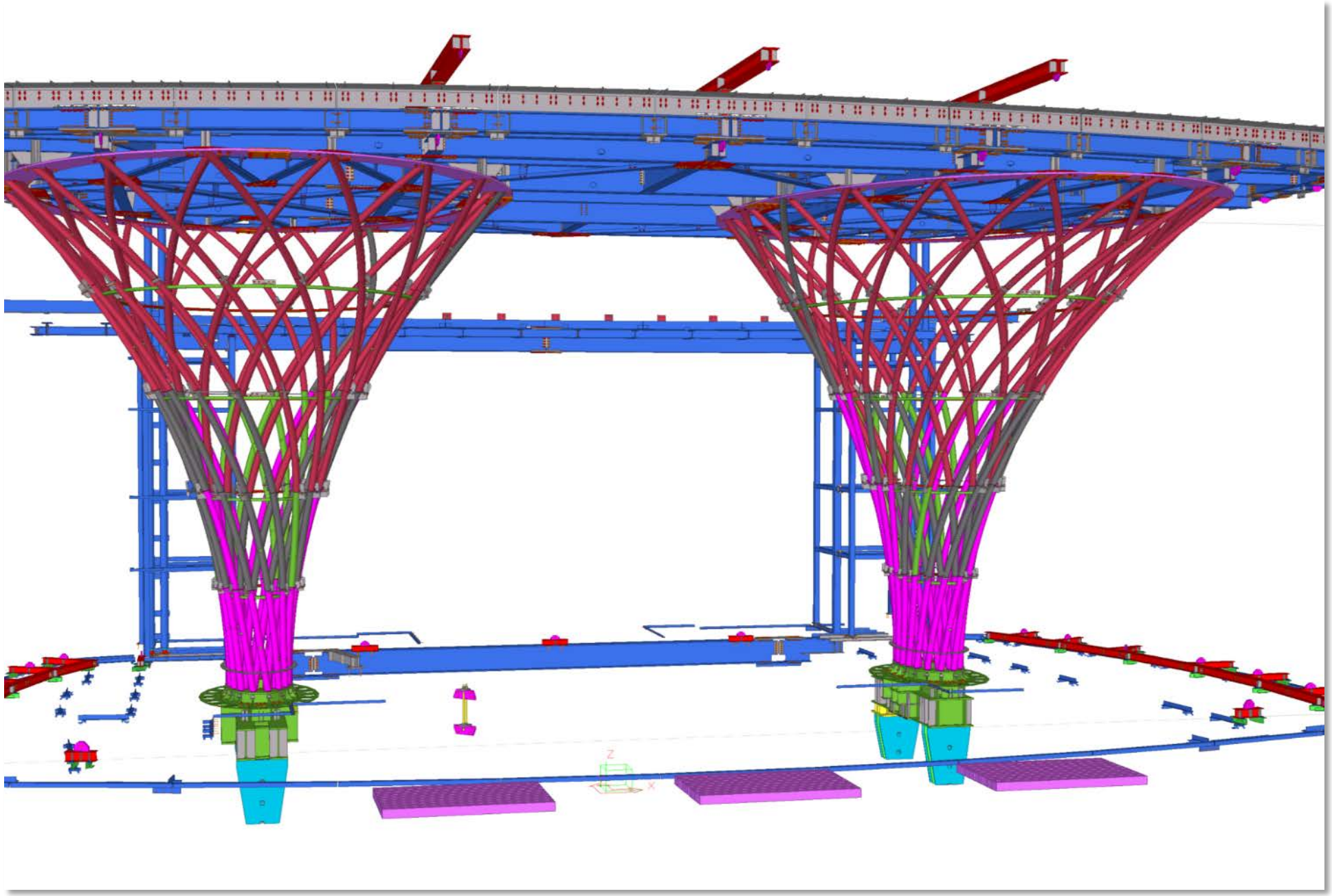
West 8

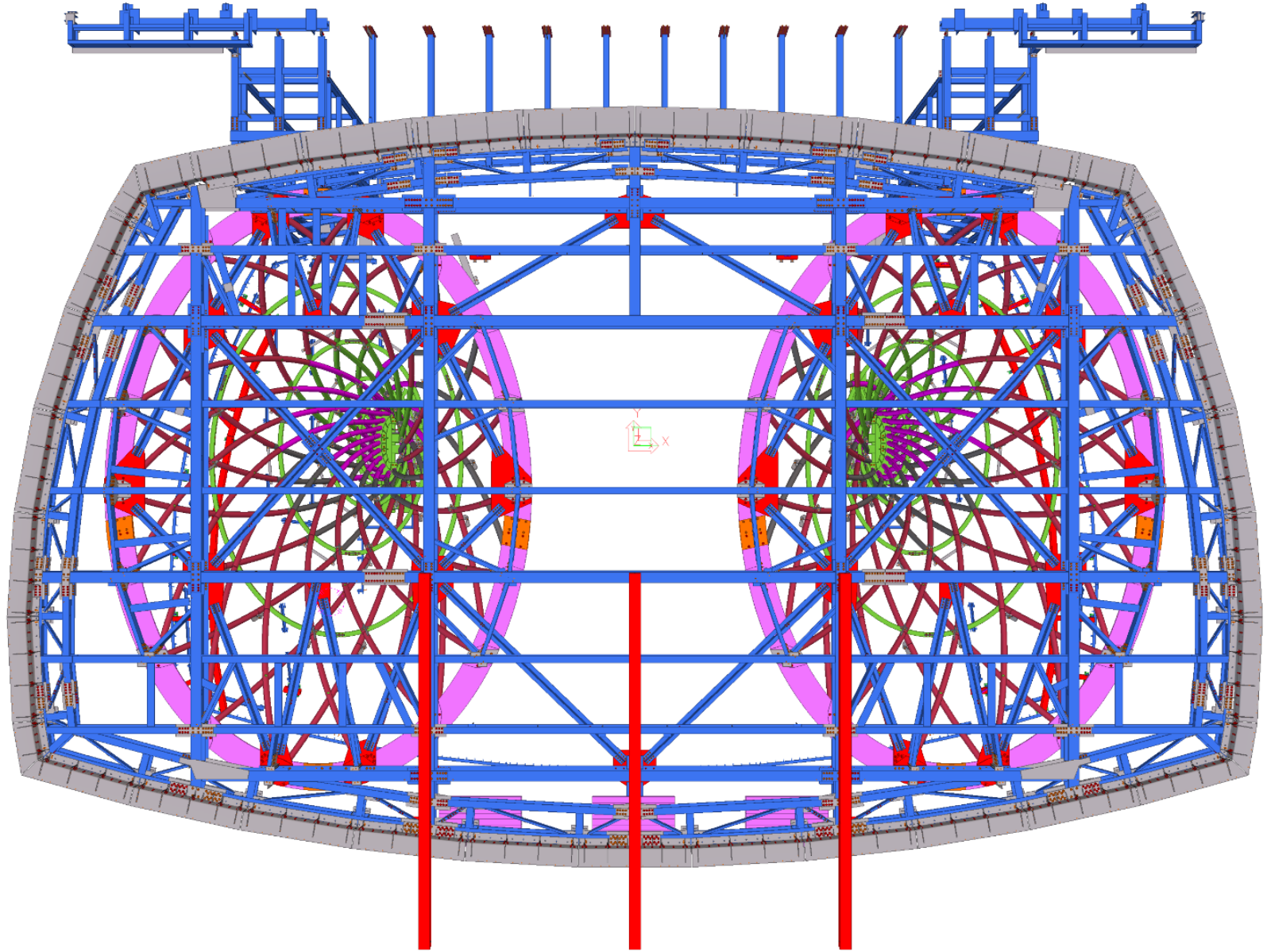
Miami Beach Soundscape

This project uses aluminum tubes that have been curved in a very complex way to create this outdoor pergola.

Pelli Clarke Pelli Architects

World Financial Center Entry Pavilion | New York City, NY






PUNTA CANA
REPUBLICA DOMINICANA
EMPTY
FULL
PRAXAIR

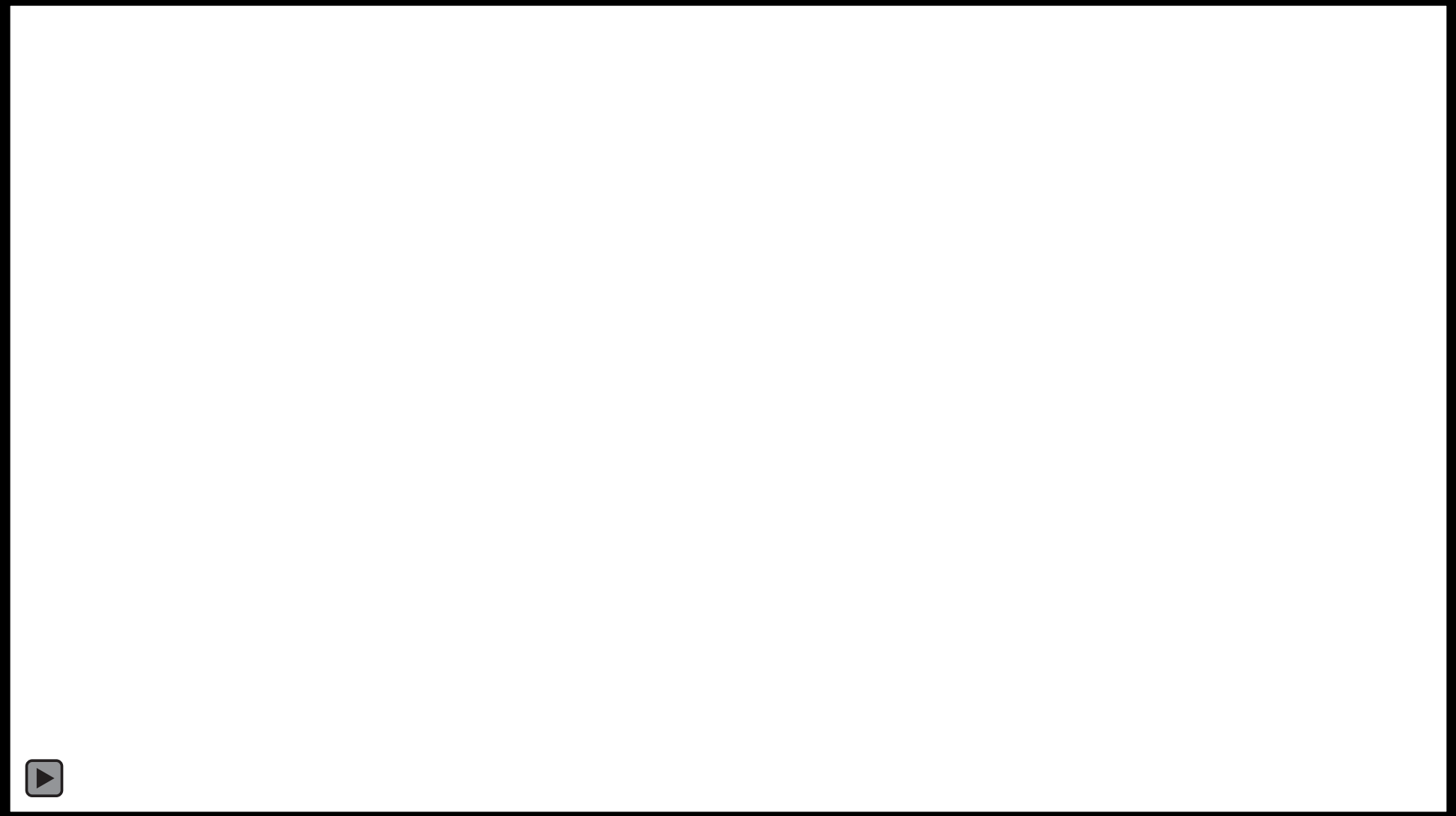

SCRAP


Bott


ACME TOOL CO.
WILE. E. COYOTE "GENIUS

Rolling plate with a 3 point pressure system

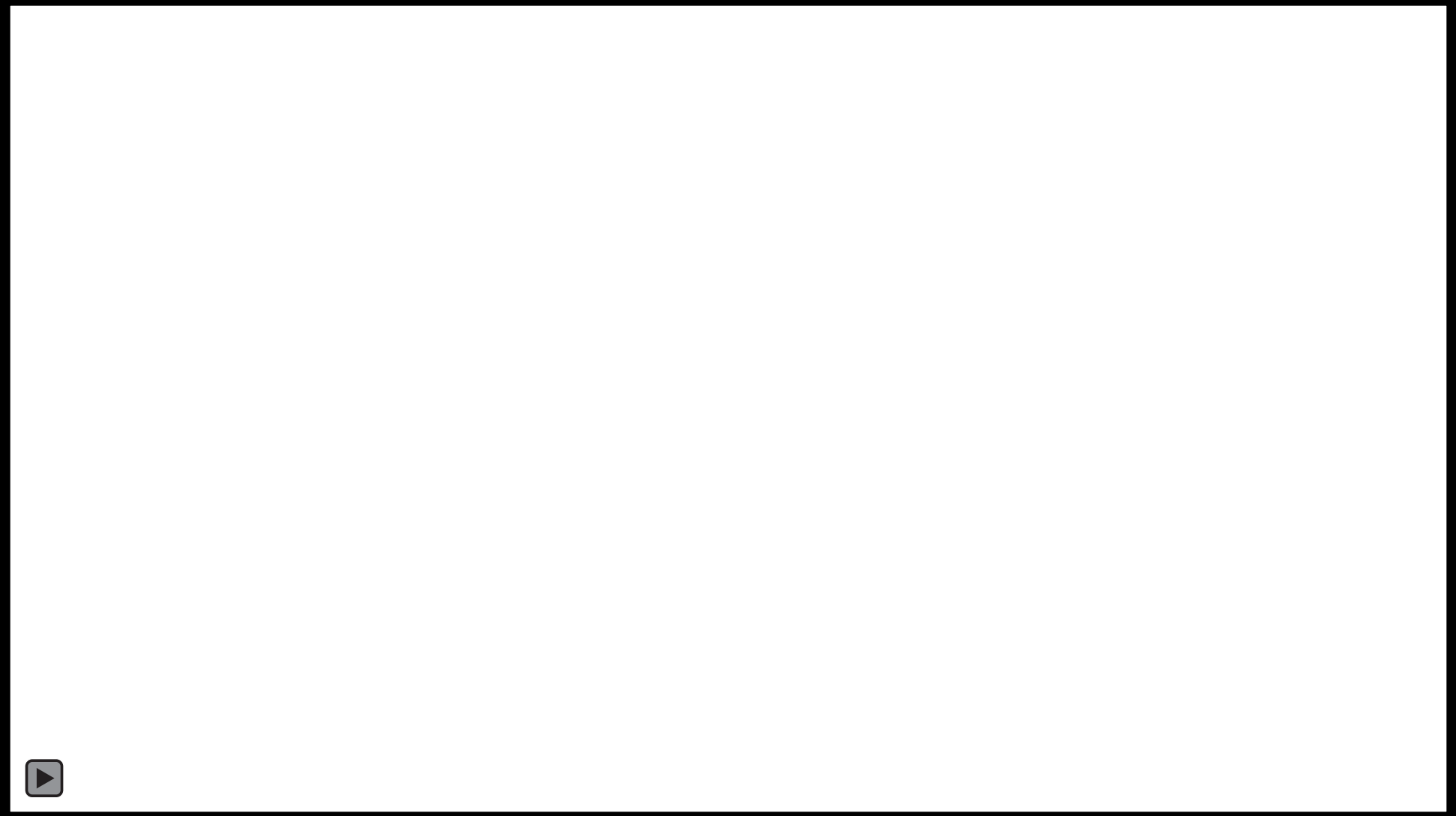
- Plate can also be rolled using this machine.




Dominique Perrault
Arganzuela Bridge | Madrid, Spain


CONCORD

Brake Forming Plate Material




60" R


Santiago Calatrava
Peace Bridge | Calgary, Canada



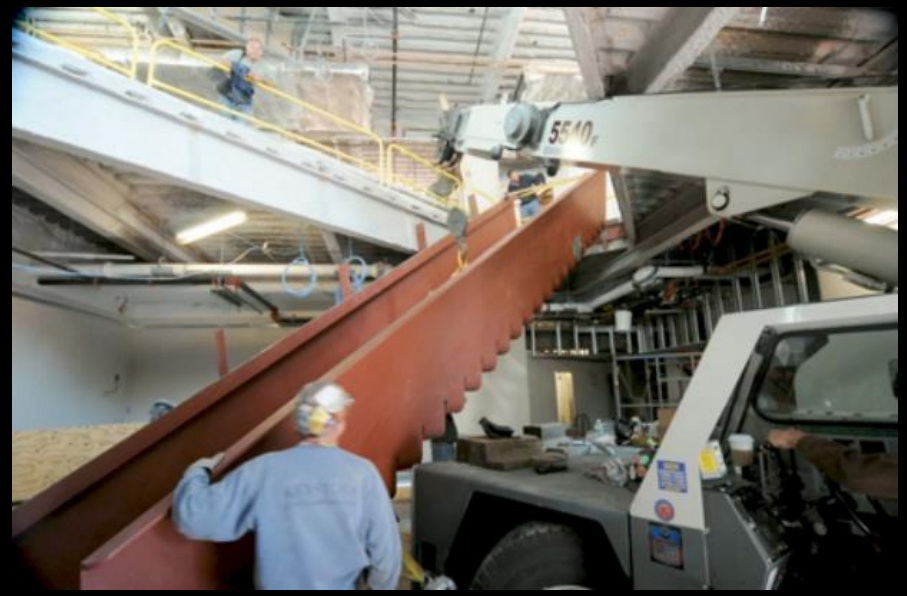

http://www.calgary.ca/Transportation/TI/Pages/Pedestrian-bridges/Peace-Bridge-image-gallery.aspx

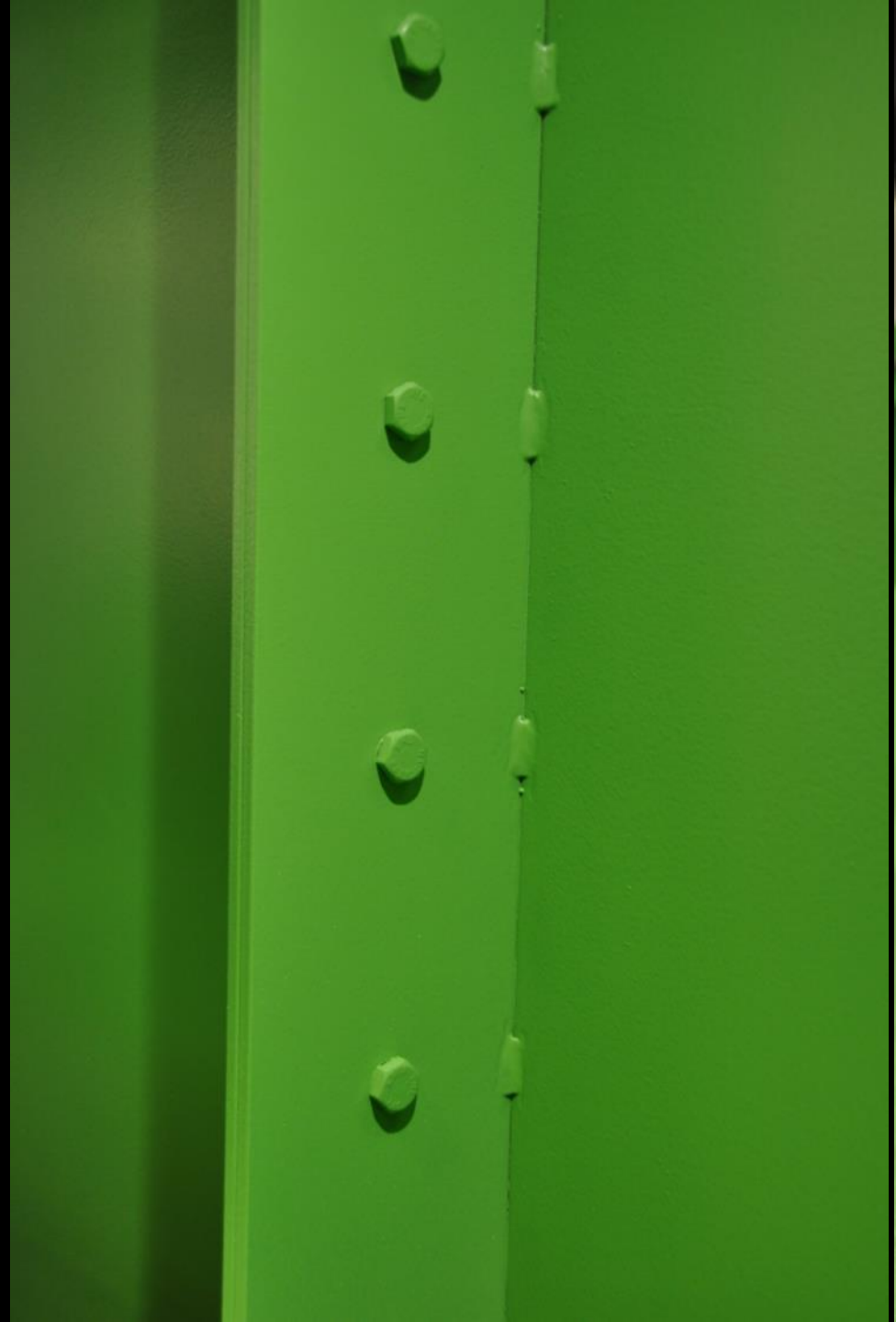
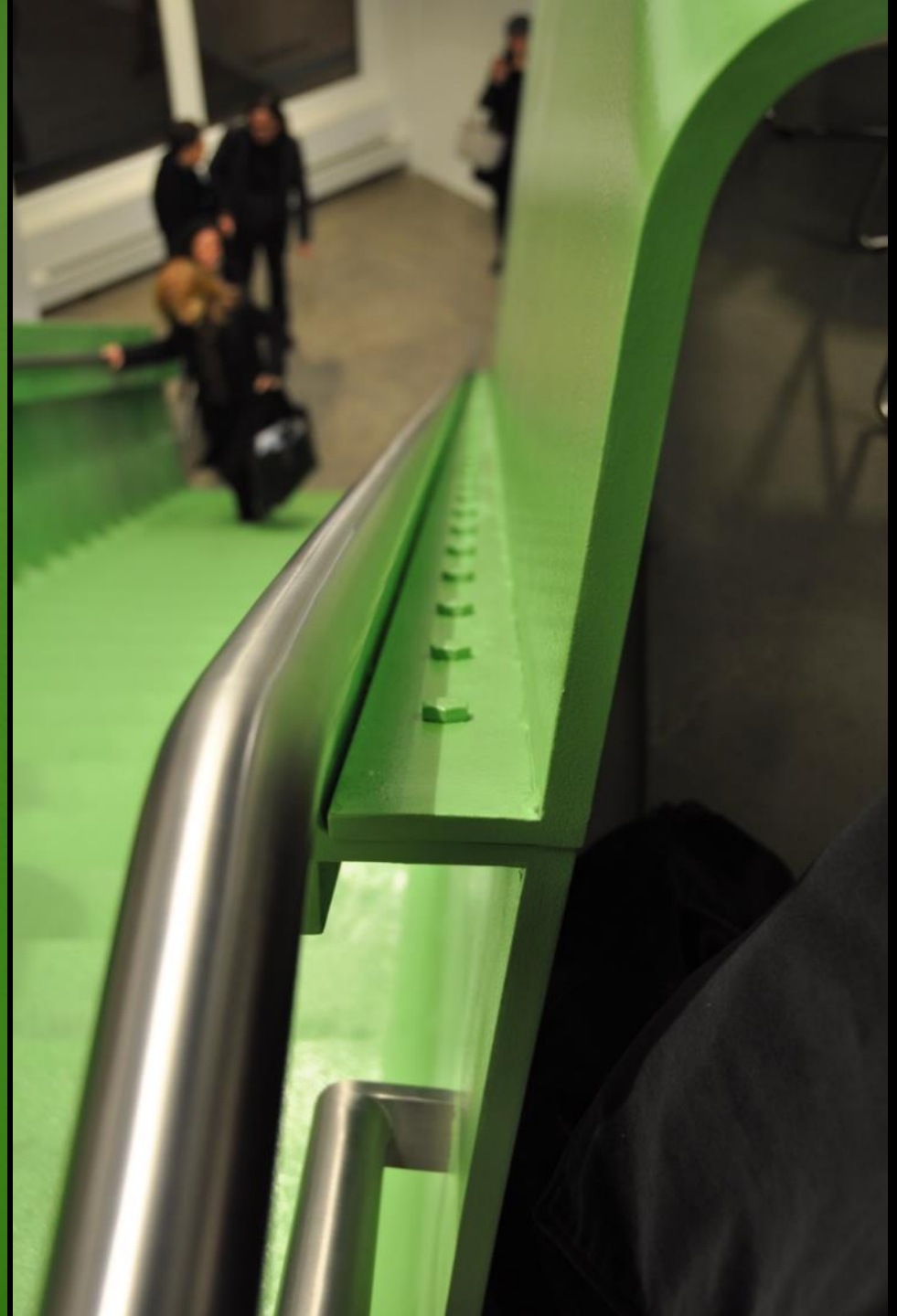
Images of the steel fabrication. All custom sections whose curvature was created via brake forming. Welds all ground smooth. AESS4

Höweler + Yoon Architecture

BSA Stair | Boston

Construction photos of the stair taken from a video of a talk given by the designer for the Boston Architectural College. For some video of the fabrication and installation: http://bsaspace.org/constructing-bsa-space/



Here on the AGO, brake forming was used to form the large plate sections into the complex curves required for the stair. Weld seams can be seen to join the wedges of the large flat portion that will provide support for the steps.

As the plate steel would not be seen, it was not important that the brake lines be unapparent.

Danish Pavilion Shanghai Expo 2010 - BIG

Much of the building was created from curved flat plate steel.

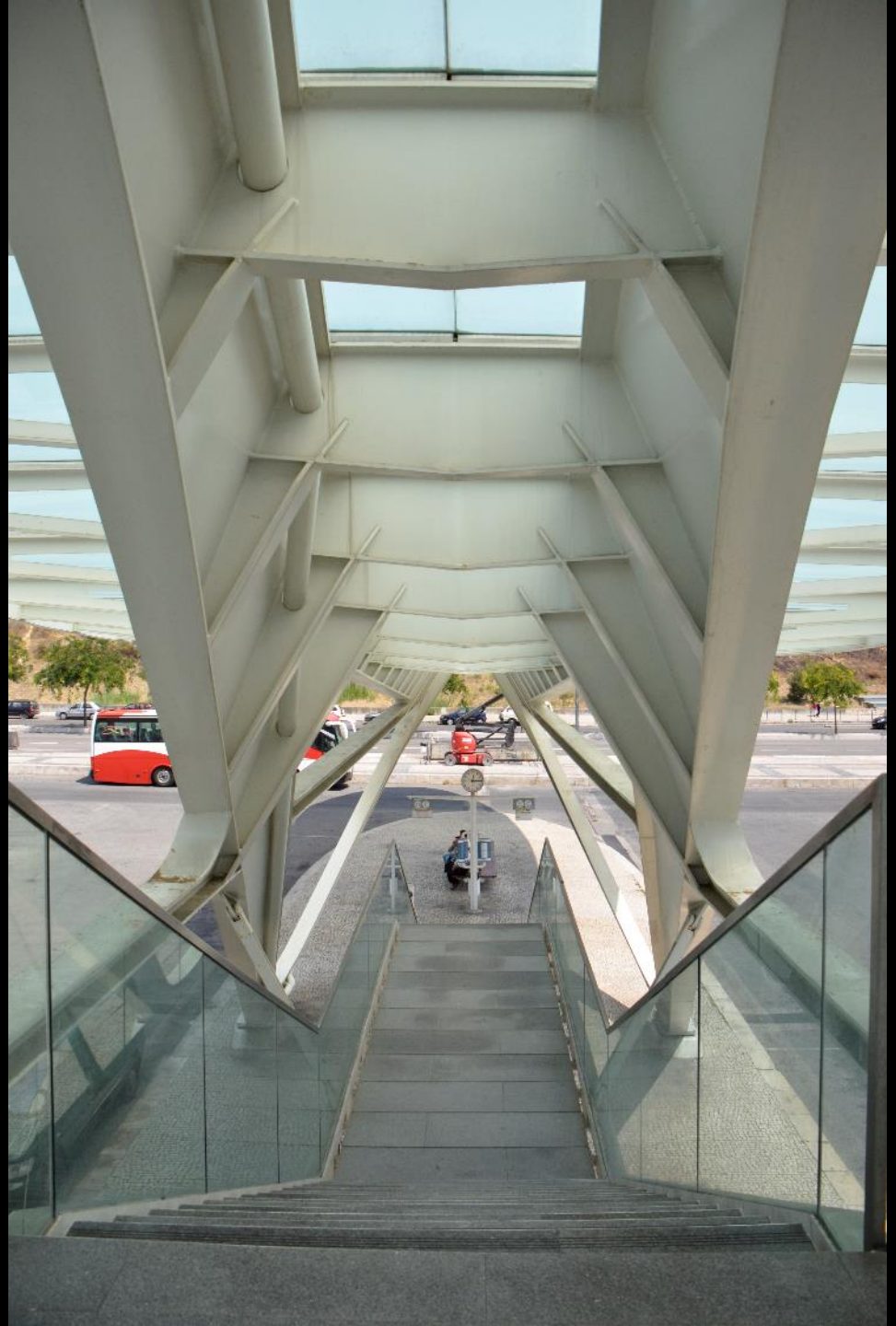
The pavilion was essentially open air, with a water feature at the centre. The gentle steps were formed from plate steel with a non skid surface applied.

Pavilion design must meet the challenges of creating interesting architecture that may or may not be permanent – and deal with different fabrication abilities.

Santiago Calatrava

Oriente Station | Lisbon, Portugal


VIAGENS TÂMEGA
SANTOS




5 D
Saída
Saída
6 D

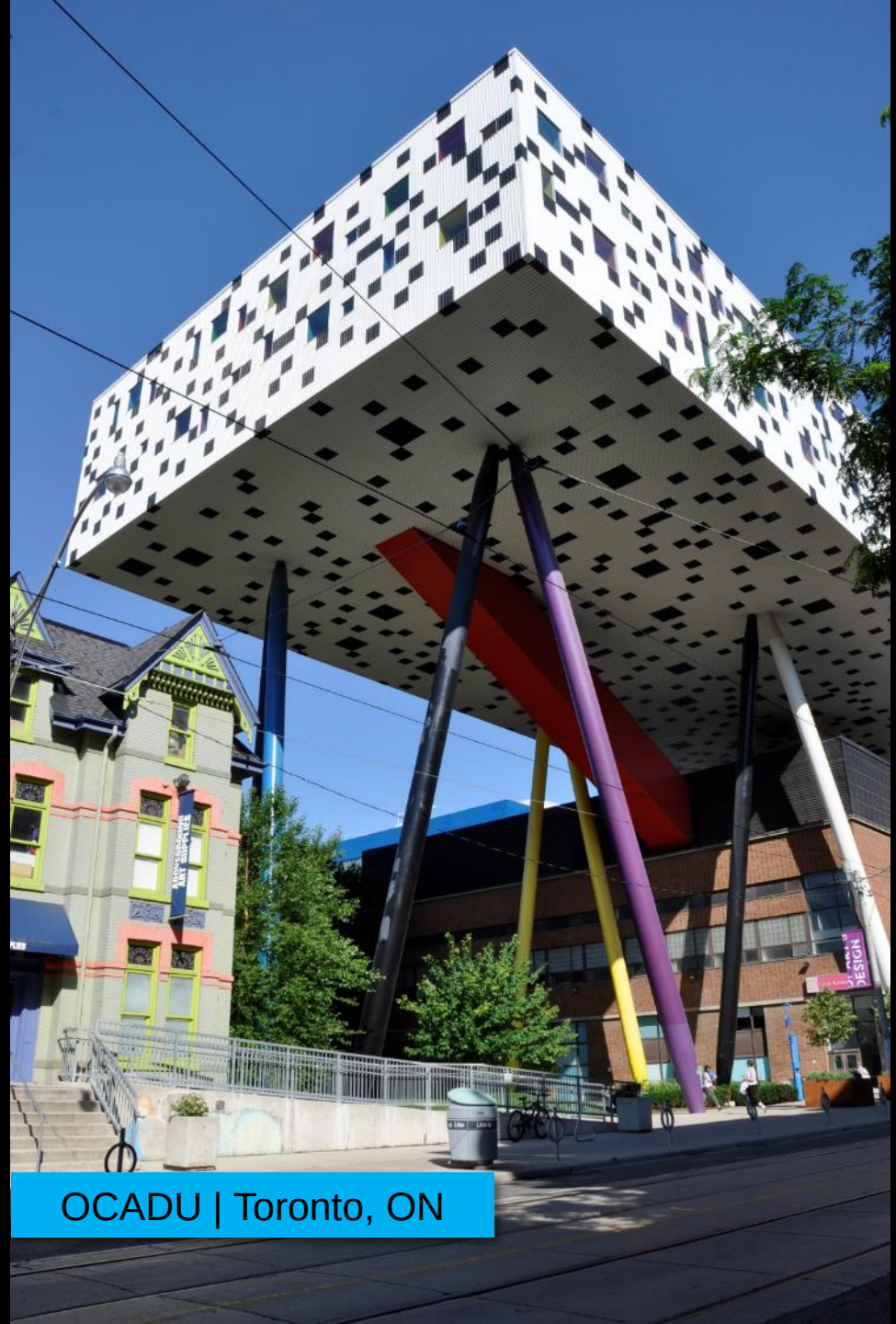
How to Create a Cone

- Always a custom shape
- Made via brake forming
- Done in sections and welded together
- Always a higher level of AESS (likely an AESS 4) due to the grinding and finishing requirements in order to make smooth the connection with the adjacent tube

Cones are made using a brake press

- Tapered tubes are not manufactured as shapes
- ALWAYS created through brake forming
- Control required to prevent lines from translating through to the good side!
- *Will fall into AESS 3 or 4 depending on detailing*

Fabrication and Erection:
Walters Inc.



OCADU | Toronto, ON

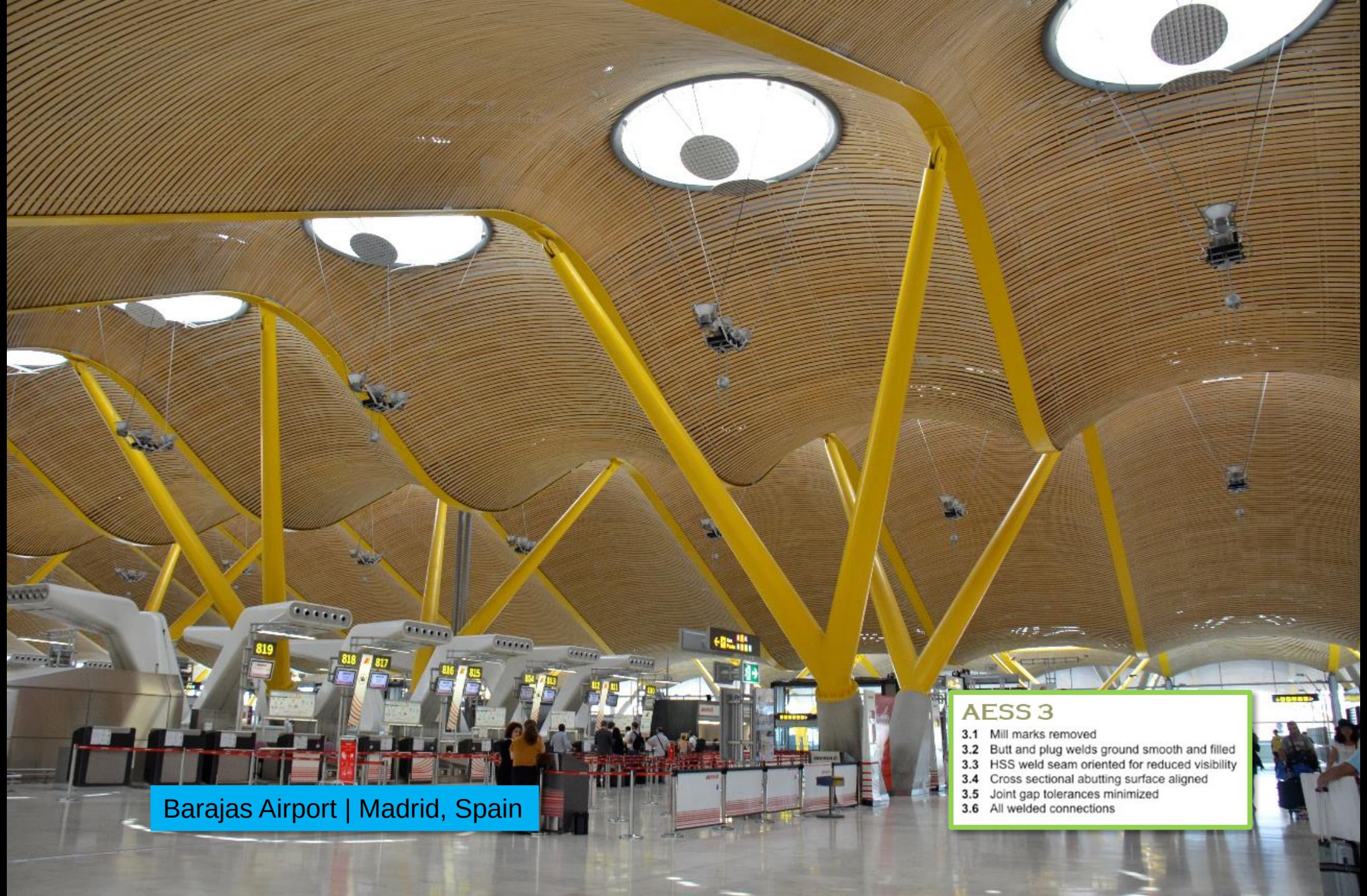

AESS 4
4.1 HSS seam not apparent
4.2 Welds contoured and blended
4.3 Surfaces filled and sanded
4.4 Weld show-through minimized

viewing distance

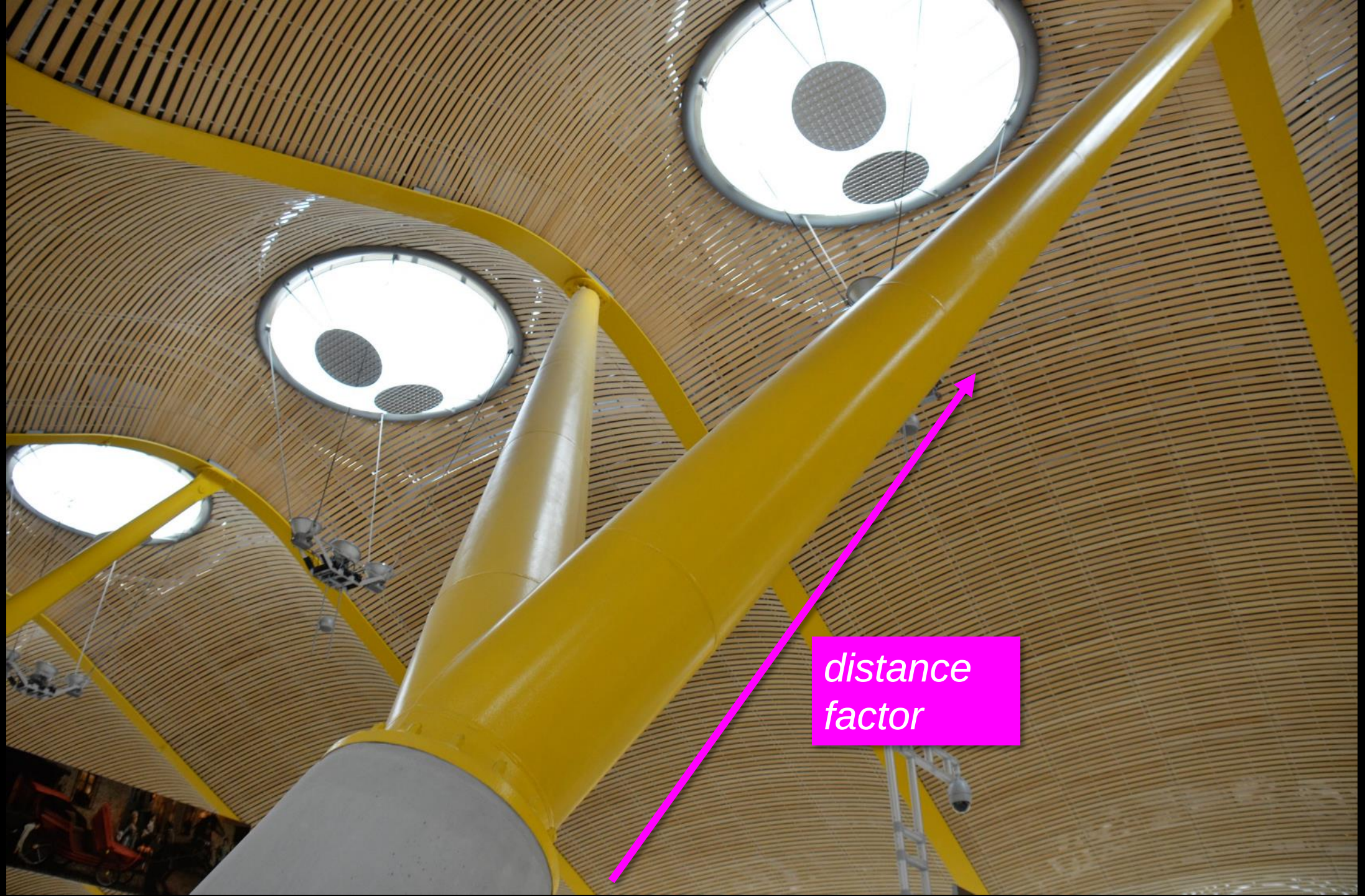
AESS 3

3.1 Mill marks removed
3.2 Butt and plug welds ground smooth and filled
3.3 HSS weld seam oriented for reduced visibility
3.4 Cross sectional abutting surface aligned
3.5 Joint gap tolerances minimized
3.6 All welded connections

Amgen Bridge | Seattle, USA



Barajas Airport | Madrid, Spain


distance
factor

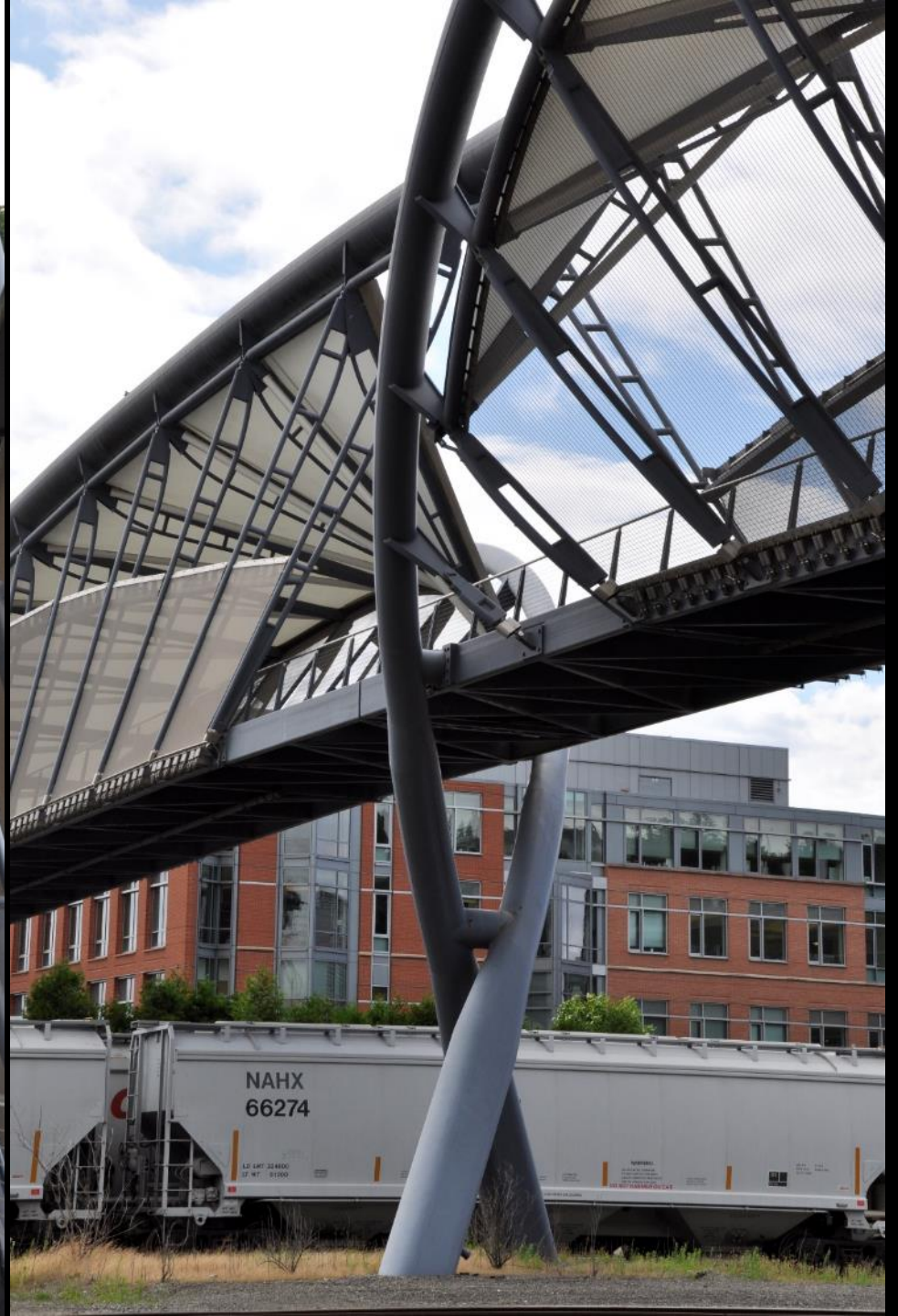
TFP Farrells

South Railway Station | Guangzhou, China

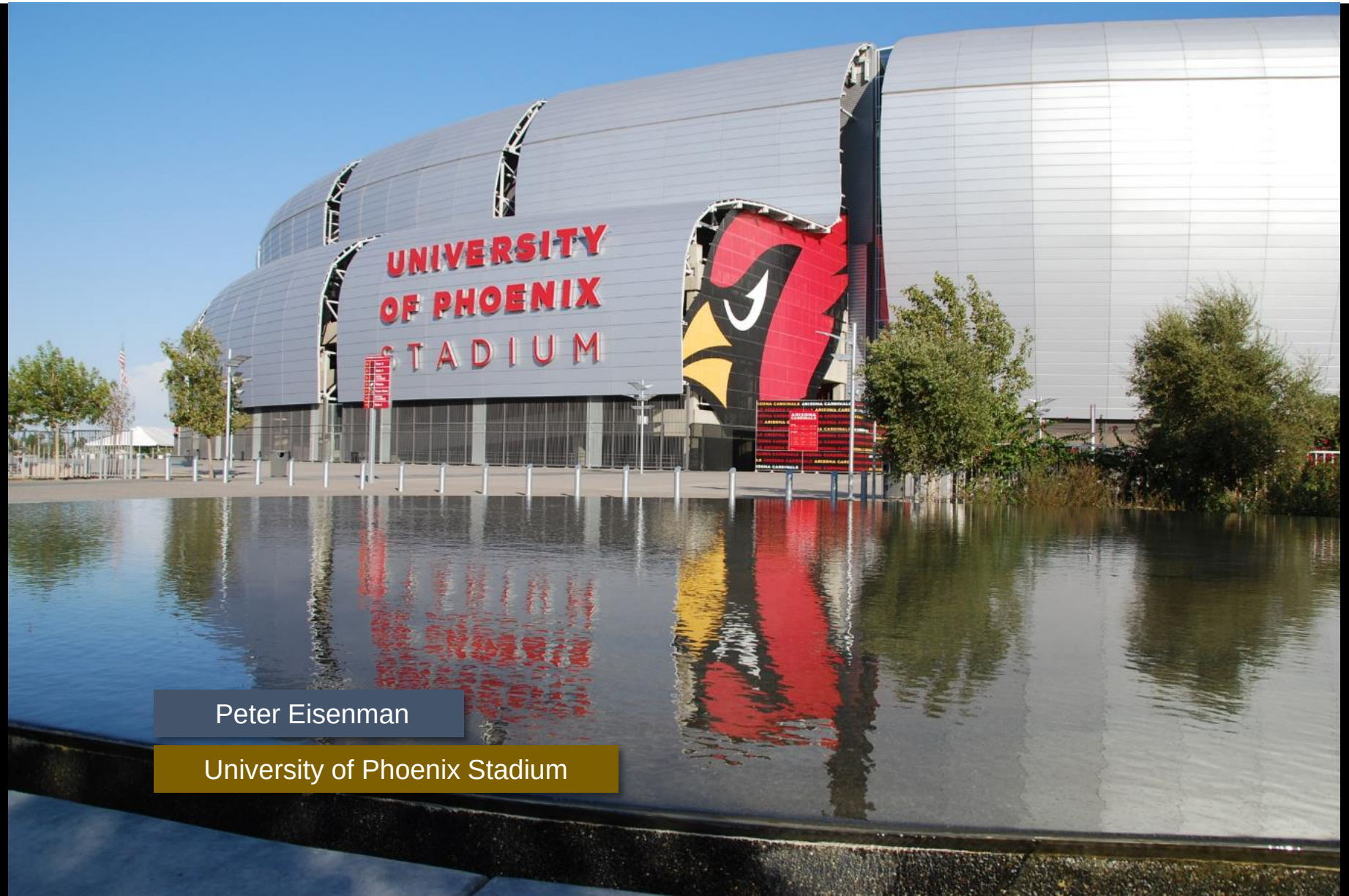
Induction bending

This sort of specific heat application process is used more for industrial pipe rather than architectural applications.


Johnson Architecture
Amgen Helix Bridge | Seattle, WA


NAHX
66274

Facet the Building to Give the Impression of Curvature



Peter Eisenman

University of Phoenix Stadium

Cut Curved Forms out of Plate Material


Frank Gehry
EMP | Seattle, WA


Paul Andreu
Beijing National Theater | China

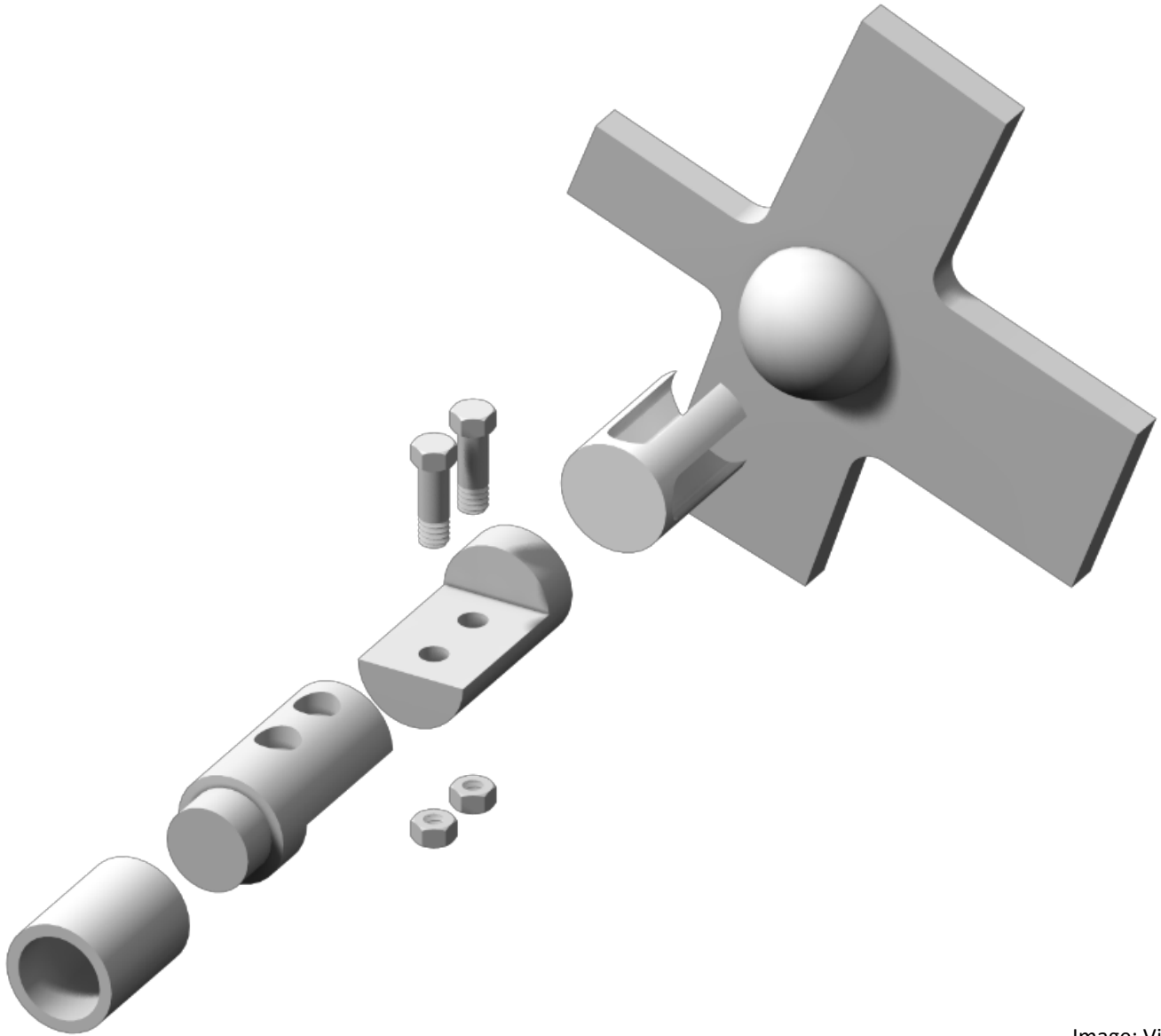
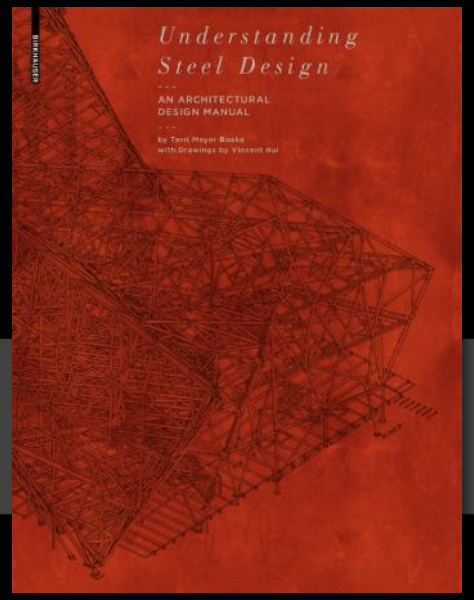
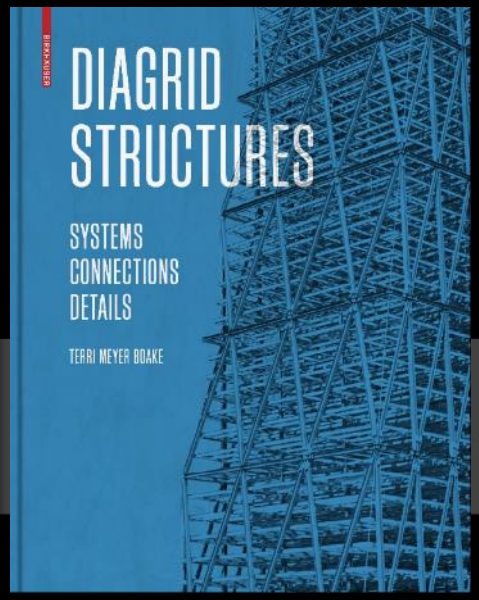
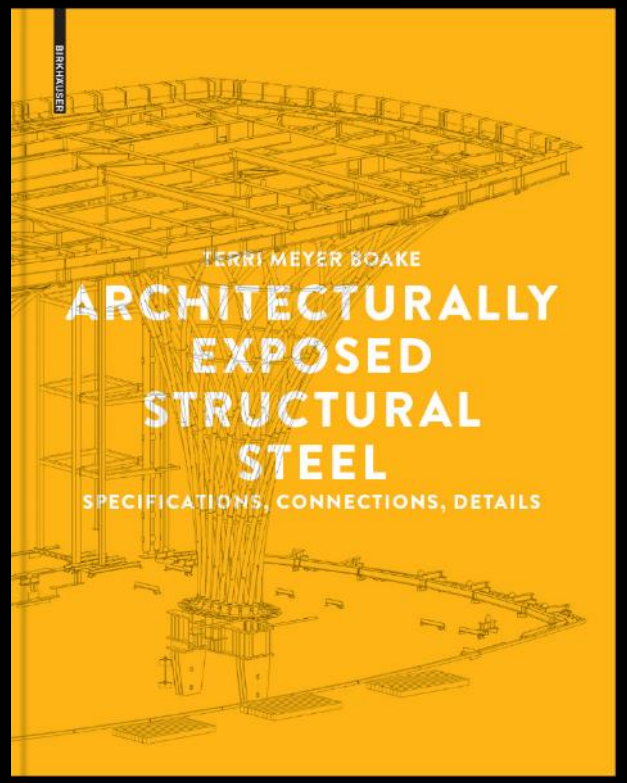


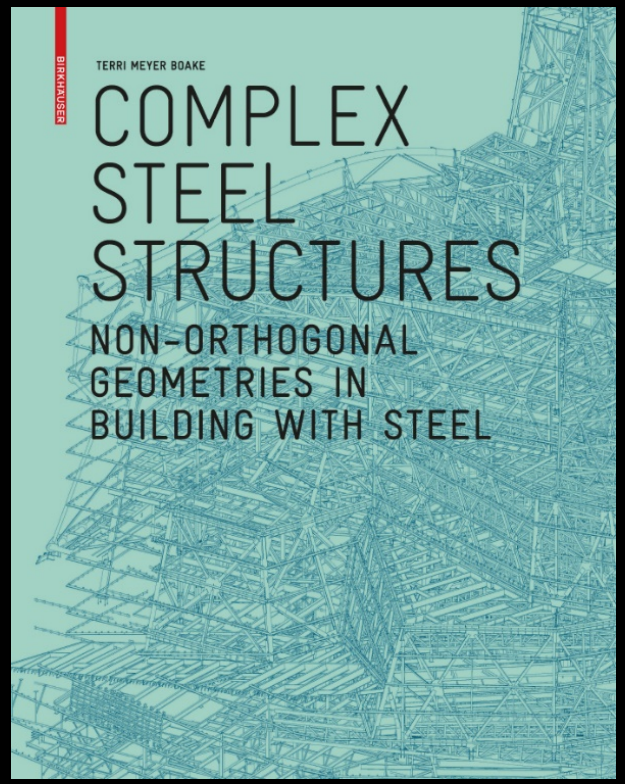
Image: Vincent Hui

STEEL


Understanding
Steel Design
AN ARCHITECTURAL
DESIGN MANUAL


DIAGRID
STRUCTURES
SYSTEMS
CONNECTIONS
DETAILS
TERRI MEYER BOAKE


TERRI MEYER BOAKE
ARCHITECTURALLY
EXPOSED
STRUCTURAL
STEEL
SPECIFICATIONS, CONNECTIONS, DETAILS


TERRI MEYER BOAKE
COMPLEX
STEEL
STRUCTURES
NON-ORTHOGONAL
GEOMETRIES IN
BUILDING WITH STEEL