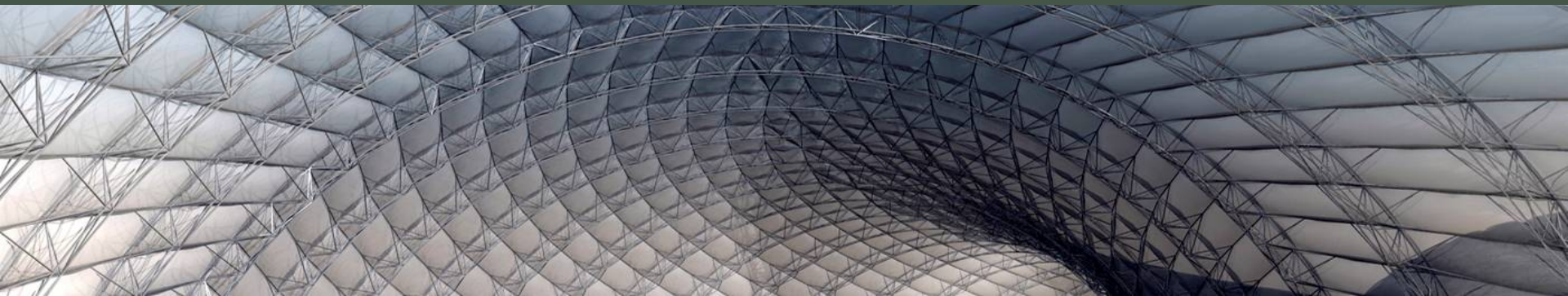
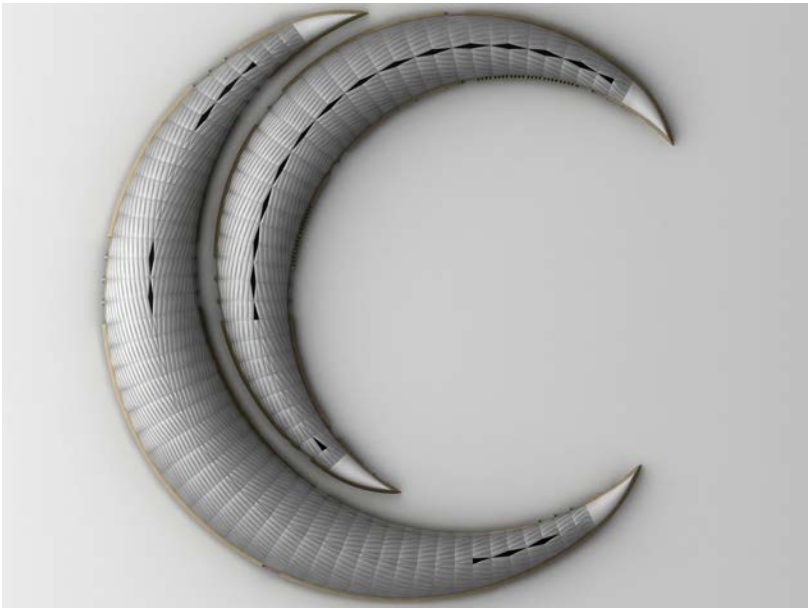
Engineering Complex Geometry Structures

Buro Happold Hong Kong
Rob May

Buro Happold



- **Complex Geometry Structures**
- **Structural Tools for Complex Geometry**
- **Building Information Modelling for Complex Geometry**
- **Example Early Projects**
- **Example Recent Project**
- **goBIM**



BIM Complex Geometry Structures

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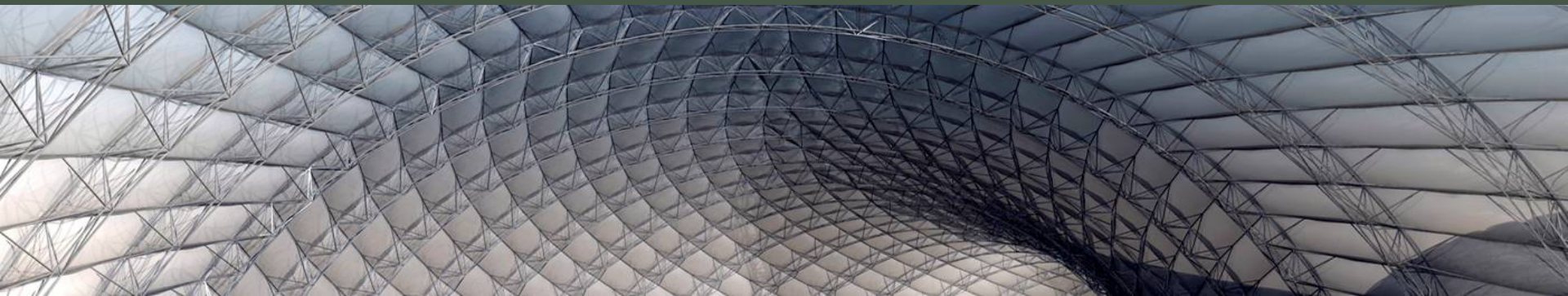
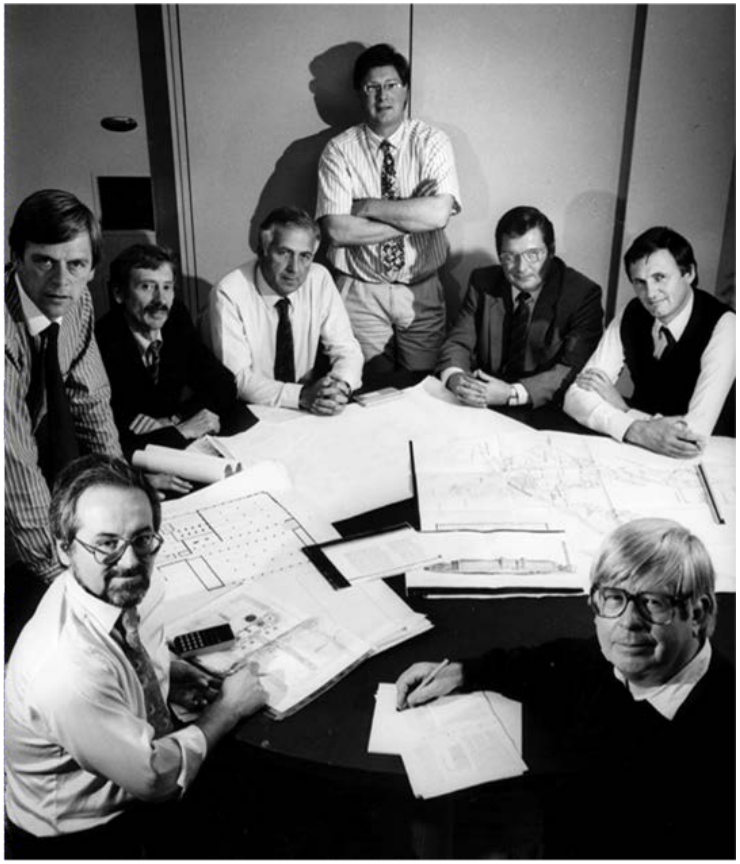


- Those with highly irregular geometric form
- Typically respond to architectural aspirations.
- May be efficient *if* appropriate tools are employed to rationalise and refine the form.


Glasgow Museum of Transport


British Museum Great Court

- Buro Happold originally developed a reputation for tensile structures.
- This specialised ability is still carried in the firm, however the company now undertakes most types of engineering activities.



BIM Complex Geometry Components

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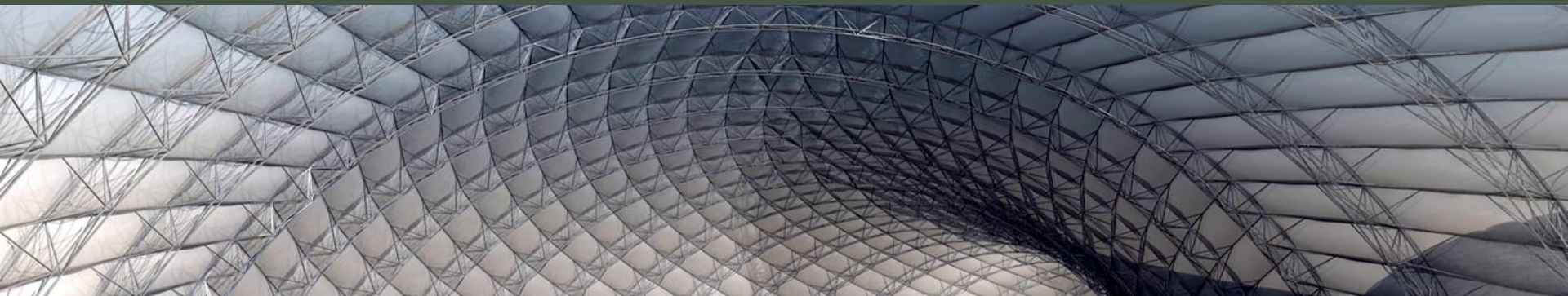


- The following are the most a selection of the most common structural systems adopted in complex geometry structure design.

Beam Structures

- Interesting forms can be generated through clever use of sequential beam elements.
- Typically manageable to generate via more conventional engineering modelling and drawing processes.

Maggie's Centre Dundee

Cork Airport, Ireland

la Rioja Alavesa Winery, Spain

Sagrada Familia School, Barcelona

Truss Structures

- Similar to beam structures, although significantly more members to model.
- As the complexity of the structure increases the process required to model the node points becomes more difficult through conventional means.

Arched Structures

- Can be highly efficient depending on dominant load effect on the structure.
- Potential for optimisation comes through formfinding the arch shape.

Sheffield Winter Garden

Space Frame Structures

- Used in two way spanning applications.
- Detailed design typically undertaken by specialist contractor (eg Novuum Structures)
- In purest form tend to provide an out-of-fashion aesthetic if exposed.

Steel Grillage Roof Structure

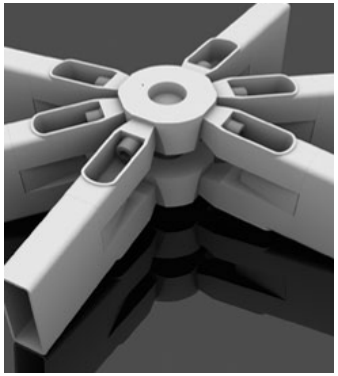

British Museum Roof


British Museum Roof

- If an appropriate form is found are extremely structurally elegant.
- Typically costly and requires significant scaffolding.
- Complex nodes which often need site welding.


Milan Fair

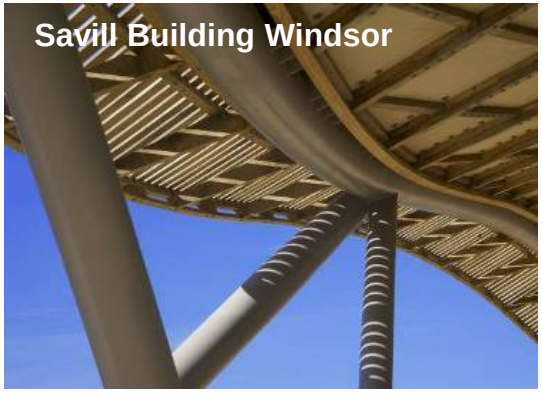

Milan Fair




Evelinas Children's Hospital

Timber Gridshell Structures

- A gridshell structure is a lattice of thin timber members laid out in an orthogonal pattern and then pushed or lowered into a doubly curved form.
- Light and efficient, but requires good edge support and even more importantly, capable contractors.



Timber Lamella Grillage Structures

- Lamella roof grids are typically square pattern but can also be rhomboidal (which can be in-filled to give triangular patterns).
- The structure provides increased bending capacity over a gridshell structure – connections may be expensive.

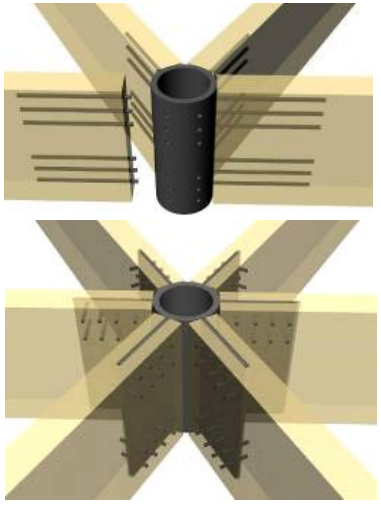
Hounslow Tube Station

Timber Geodesic Structures


Marlowe Academy

- Provide a structure that can act in both bending and membrane actions depending on the geometry.
- Bending forces can be resisted by introducing ties into the structure as per the Alnwick visitor centre, maintaining some compression in the system.
- Connections can be very expensive!


Marlowe Academy


Typical Node Connection Details

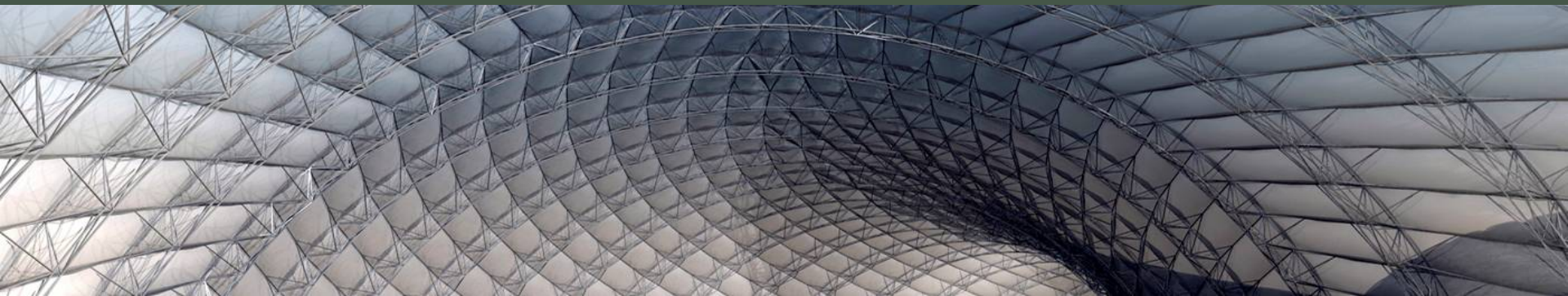

Alnwick Visitor Centre

- Tensile Structures require specialist analysis typically involving a form finding process. Can be light and elegant solutions

- Pneumatic structures are those with inflated cladding systems like ETFE or PTFE. These are mounted on structural subframes and are again extremely light.

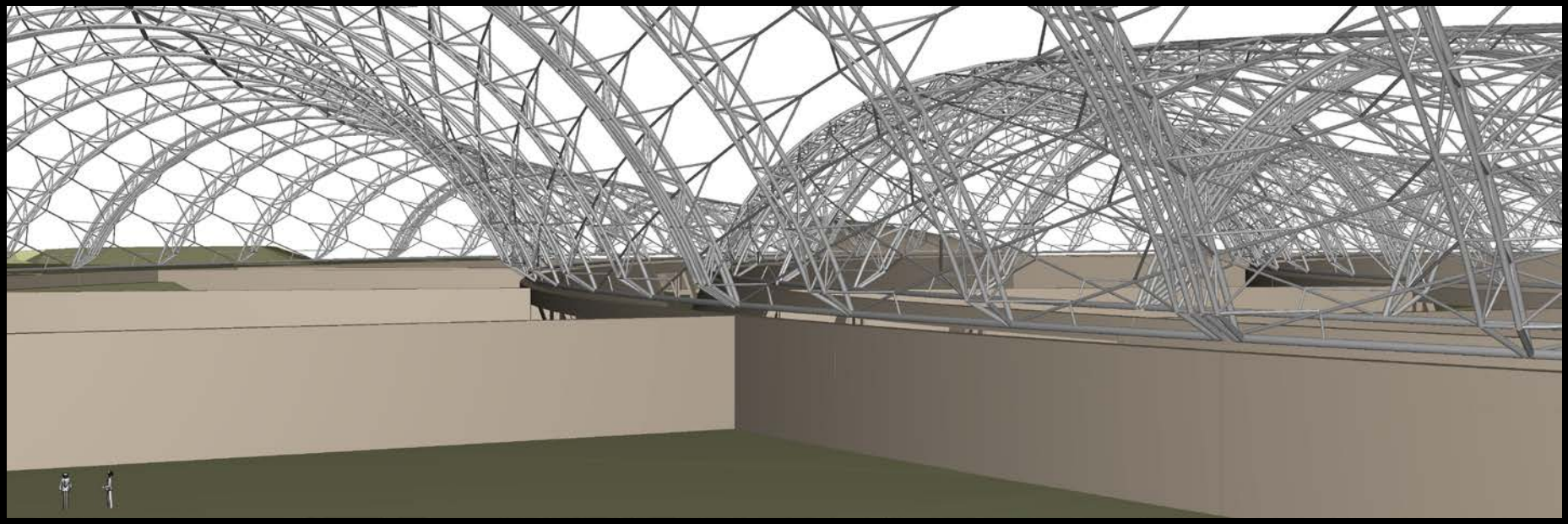
BIM Tools for Complex Structures

Buro Happold

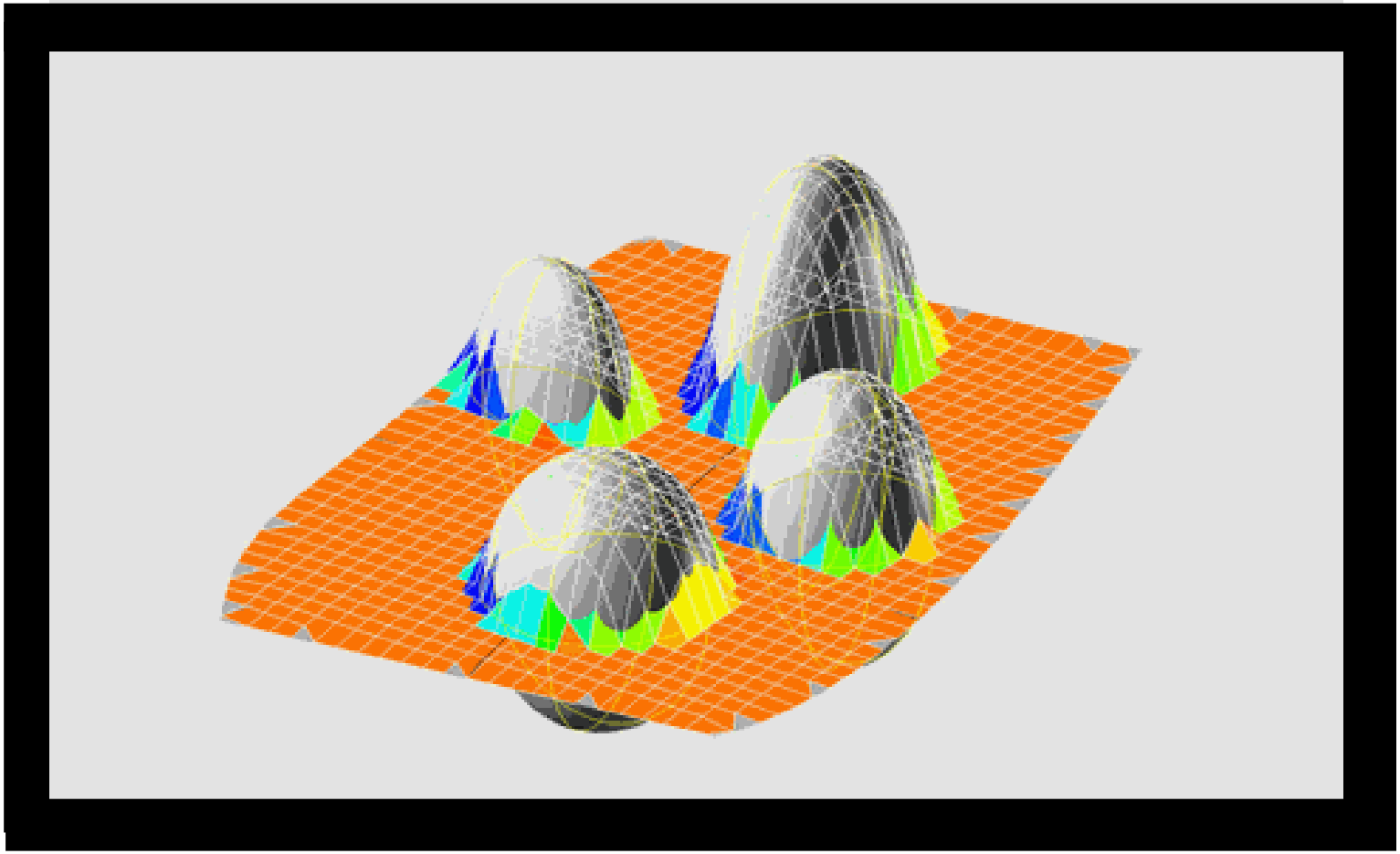


Key activities that are likely to require the structural engineer's attention are:

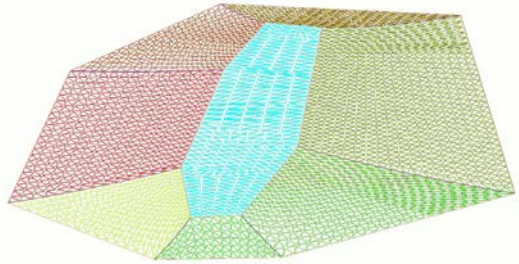
- Formfinding
- Optimisation
- Panelisation
- Form to Fabrication
- Advanced Analysis



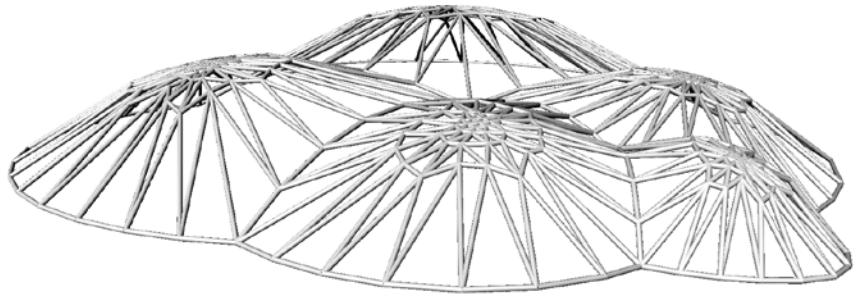
- Fabric structures
- Minimal surfaces
- Efficient shapes



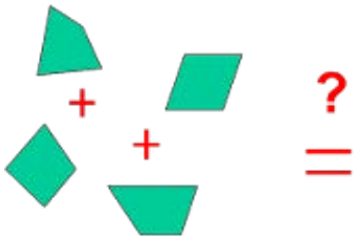
Form



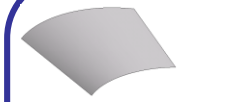
Scunthorpe Sports Academy



Grid

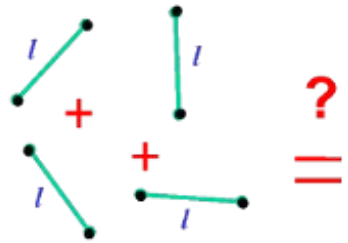


Flat 4-sided panels

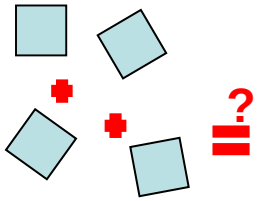


Singly curved (Many)

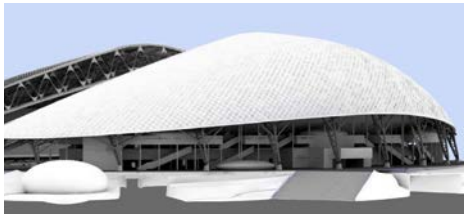
Doubly curved (Few)

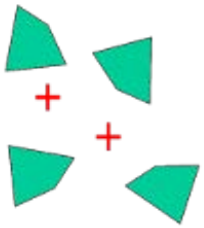


Equal length members

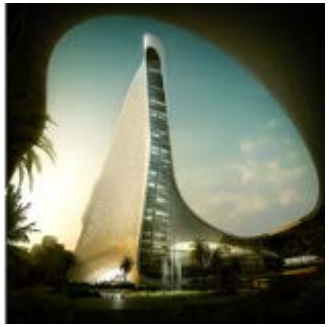


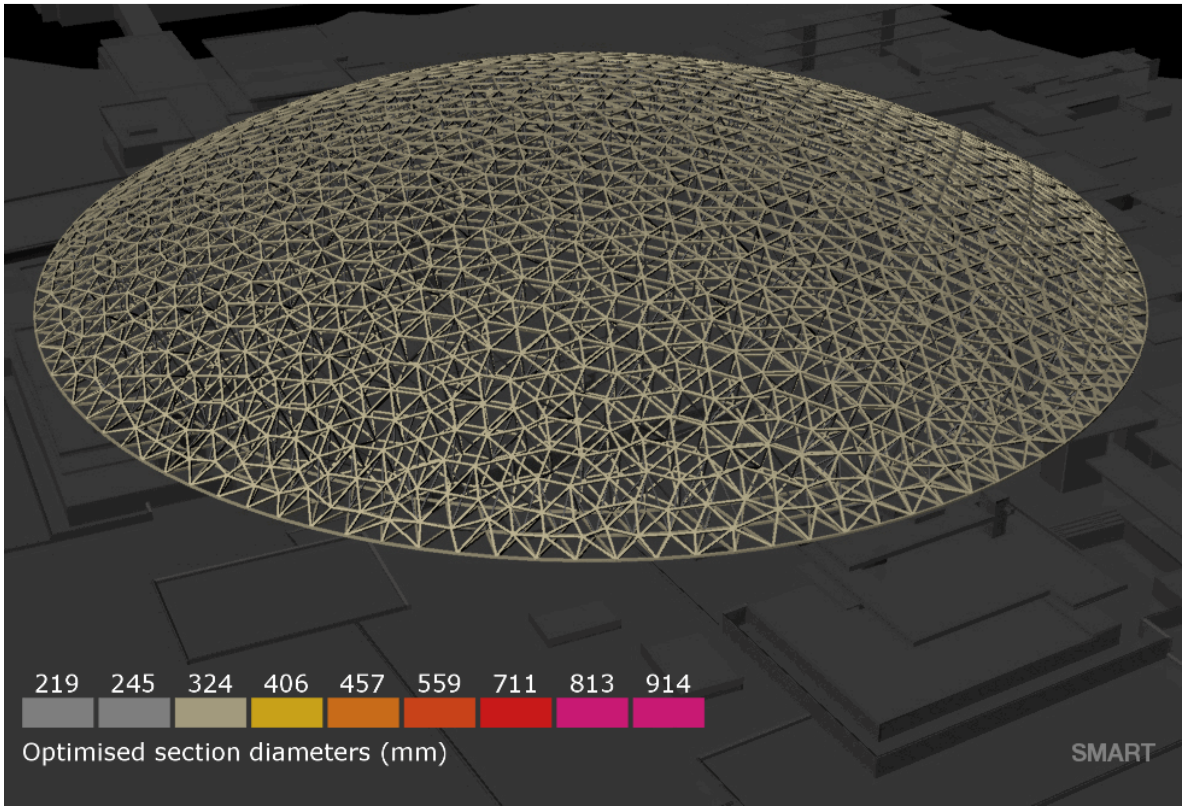
Square panels

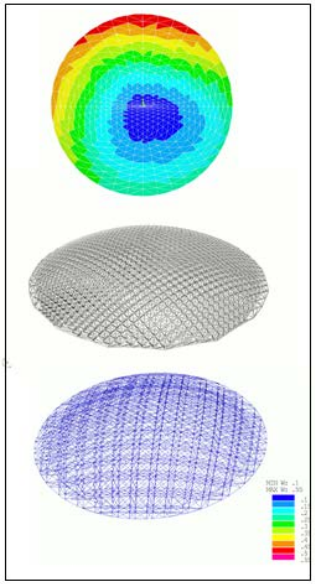




Identical panels

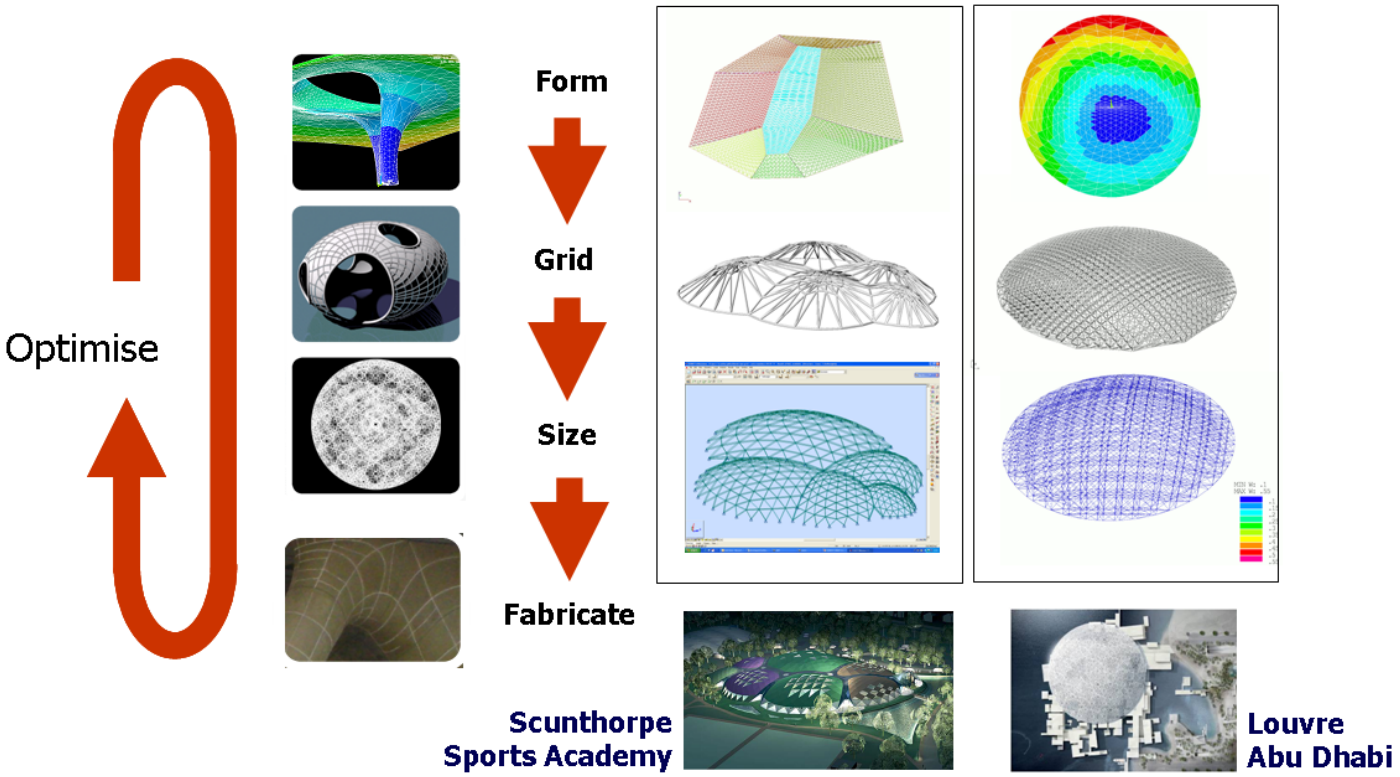




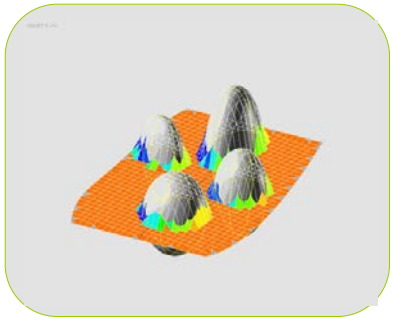


Louvre
Abu Dhabi

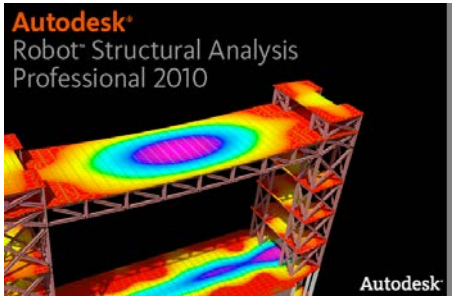
- One-step and iterative
- Stiffness, strength, buckling
- Structure, lighting, etc



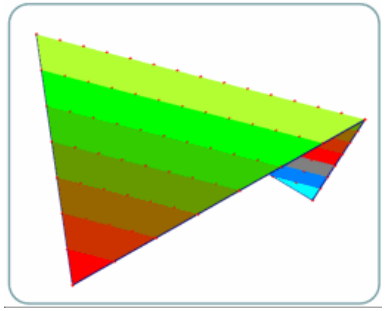
- Geometry optimisation: form and grid
- Structural optimisation: member sizing
- Digital fabrication



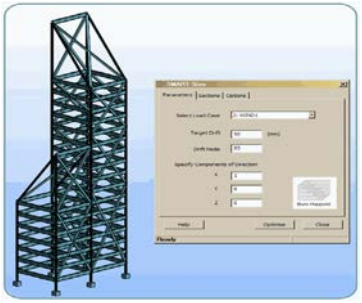
SMART Form
Surface and grid optimisation



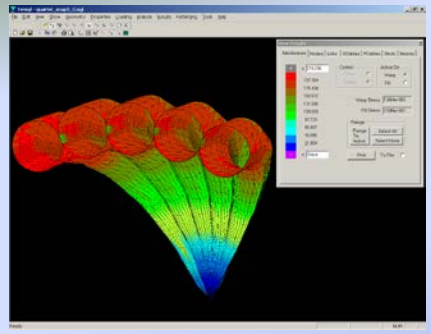
Autodesk Robot
Structural analysis



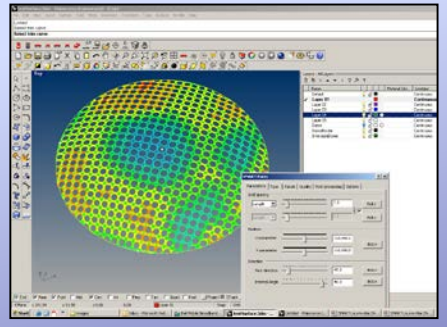
Tensyl
Fabric/form analysis/design



SMART Sizer
Structural optimisation



- Full standalone applications
- Plug-ins to Rhino, DP, RSA, Ansys, etc
- Graphic visual



BIM Using BIM for Complex Structures

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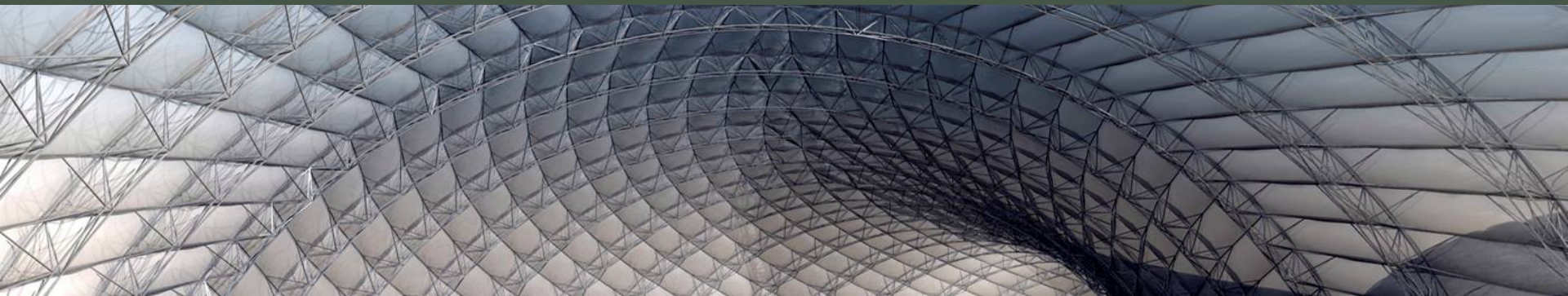
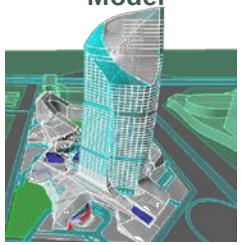
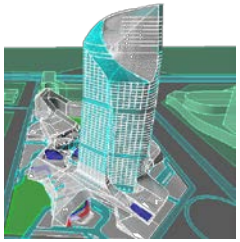


Parallel Modelling

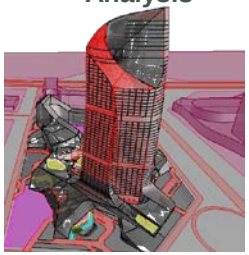
Architectural Model



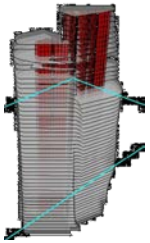
People Flow Model



Energy Analysis

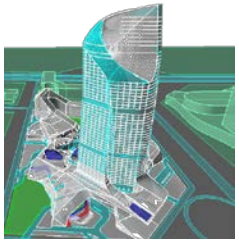


Structural Check Model



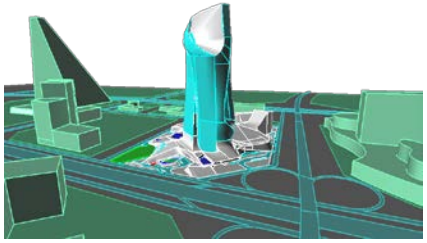
Cost Analysis

Post Productions Model

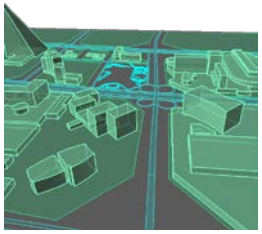


Fabrication Model

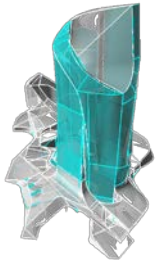
Wind Analysis



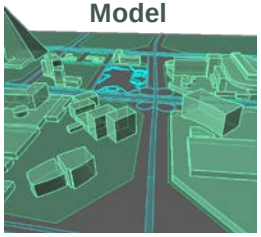
Site



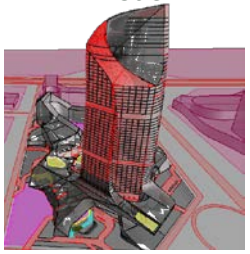
Façade Design



Civil Drainage Model



Clash Detection Model



Structural Drawing Production Model

Structural Model

Structural Model 2

Structural Model 3

Structural Model 4

Structural Model 5

Structural Model 6

Structural Model 7

Structural Model 8

Structural Model 9

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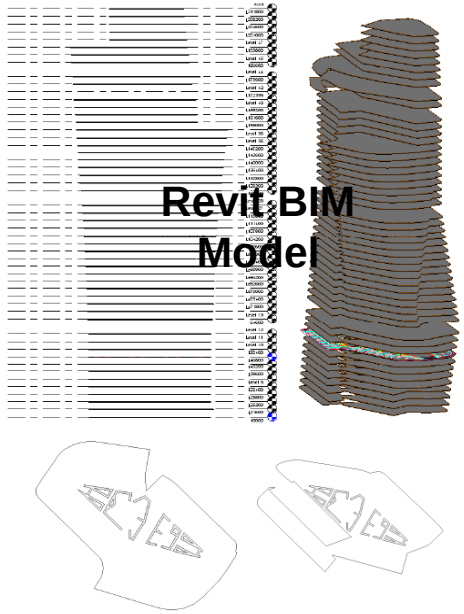
BIM Modelling – One Model



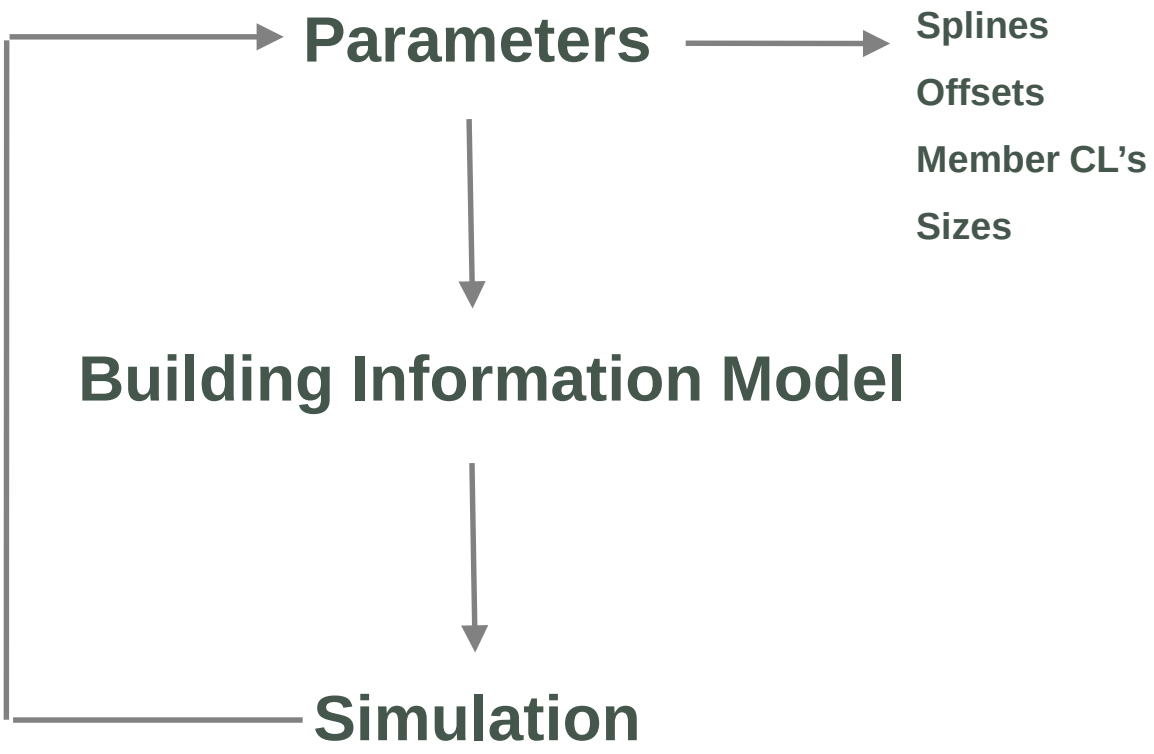
Challenge of using multiple software platforms

Custom interface tools – using API’s

Writing in-house links between Rhino – Revit – Robot - Other

- Complex/warped slabs/panels
- Positioning
- Geometric Updates
- Custom Parts/Connections
- Rhino link does not exist

BIM – Complex Structures



BIM Early Examples

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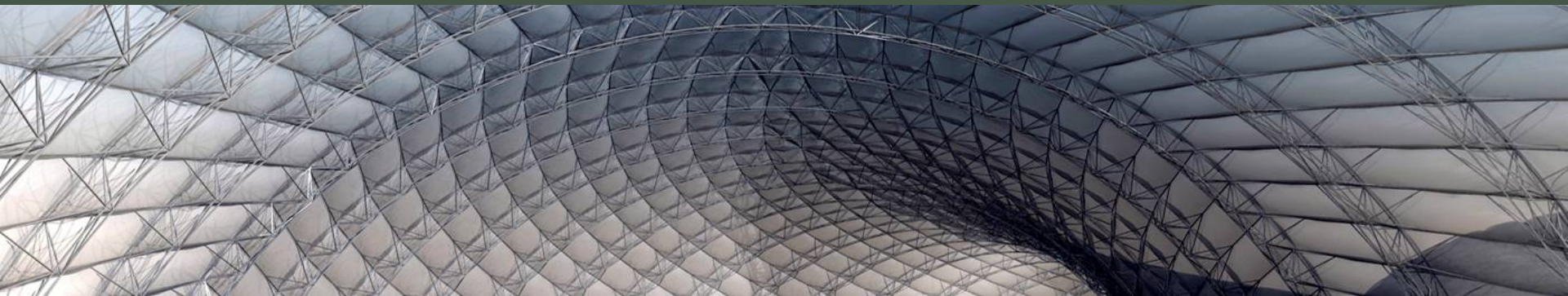
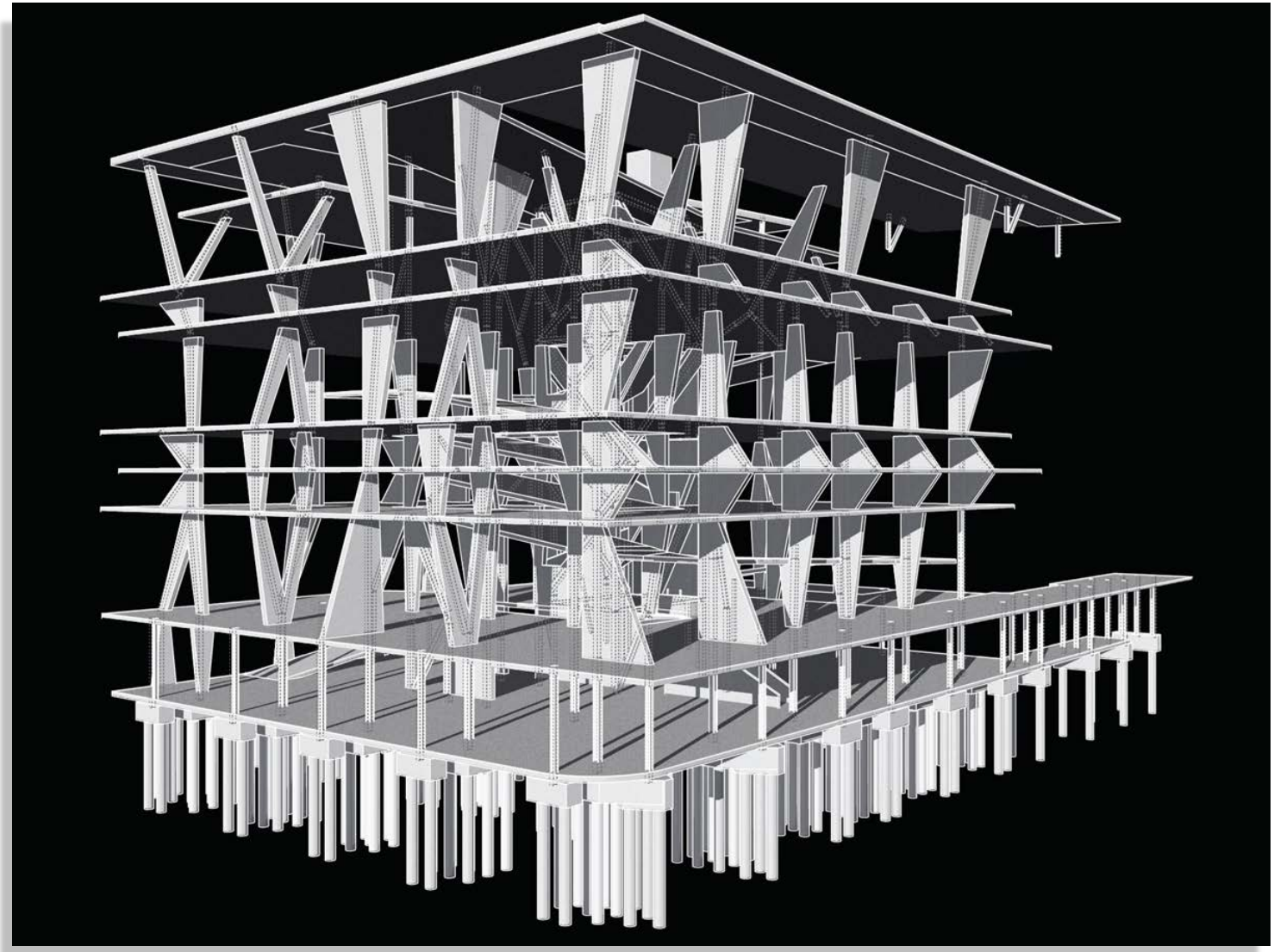
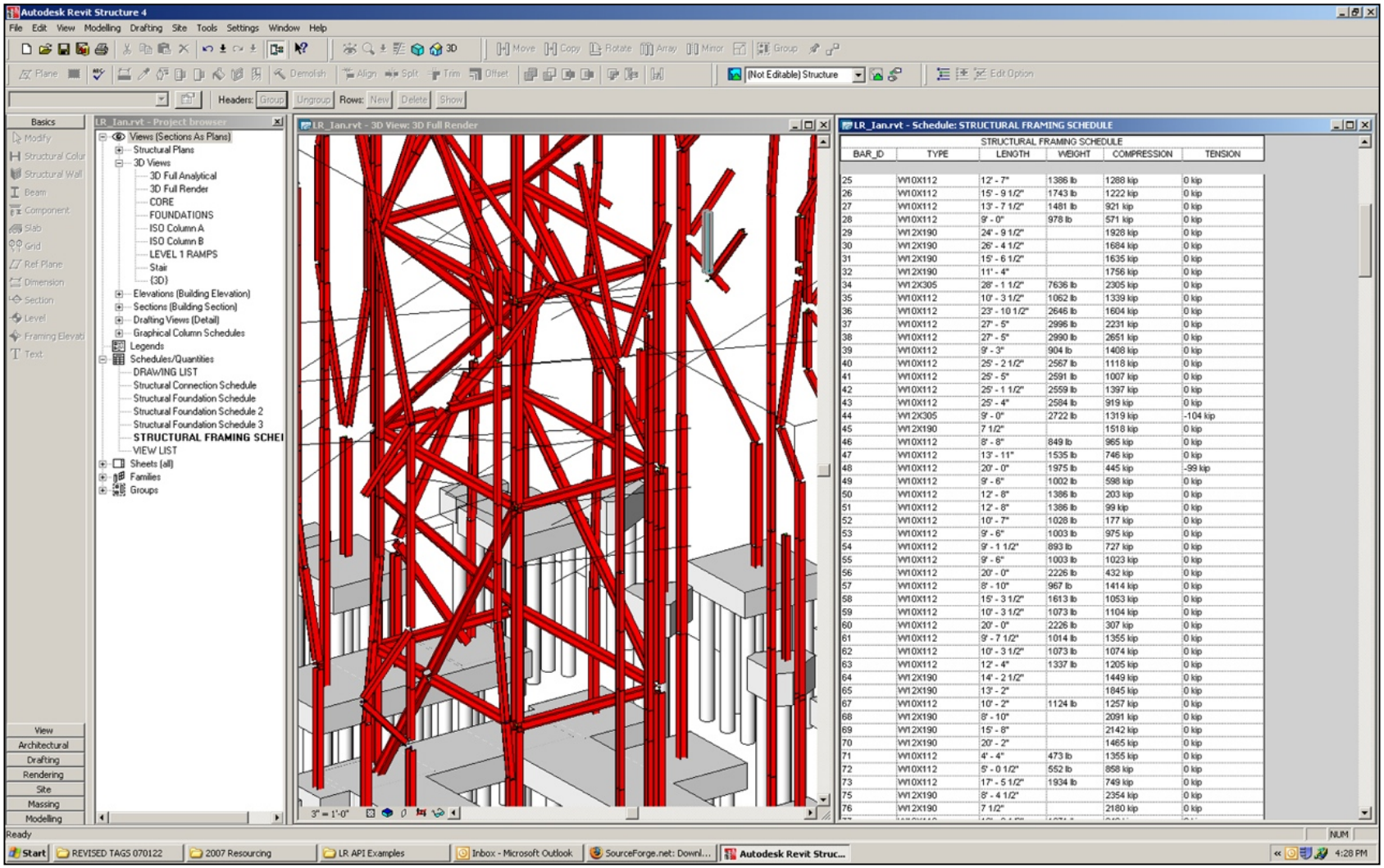
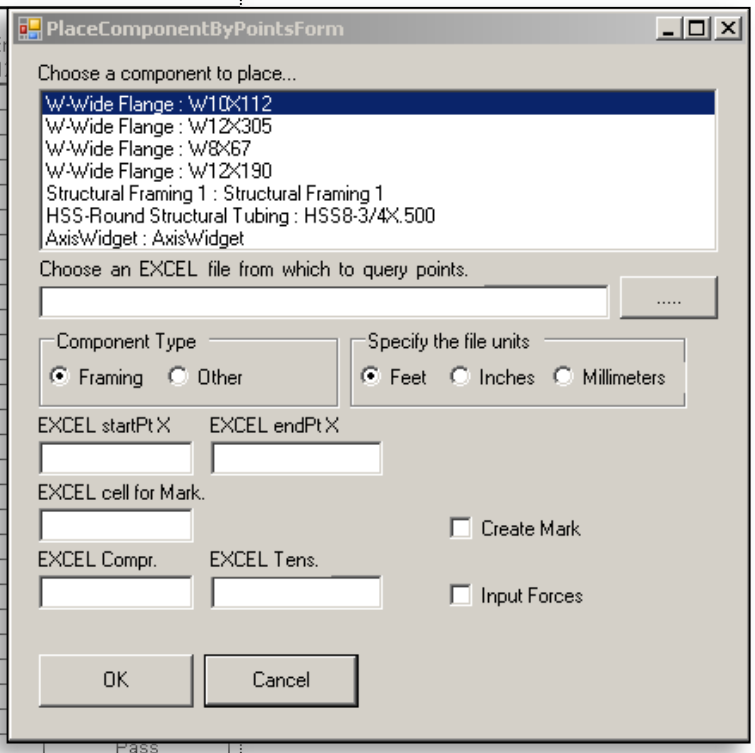


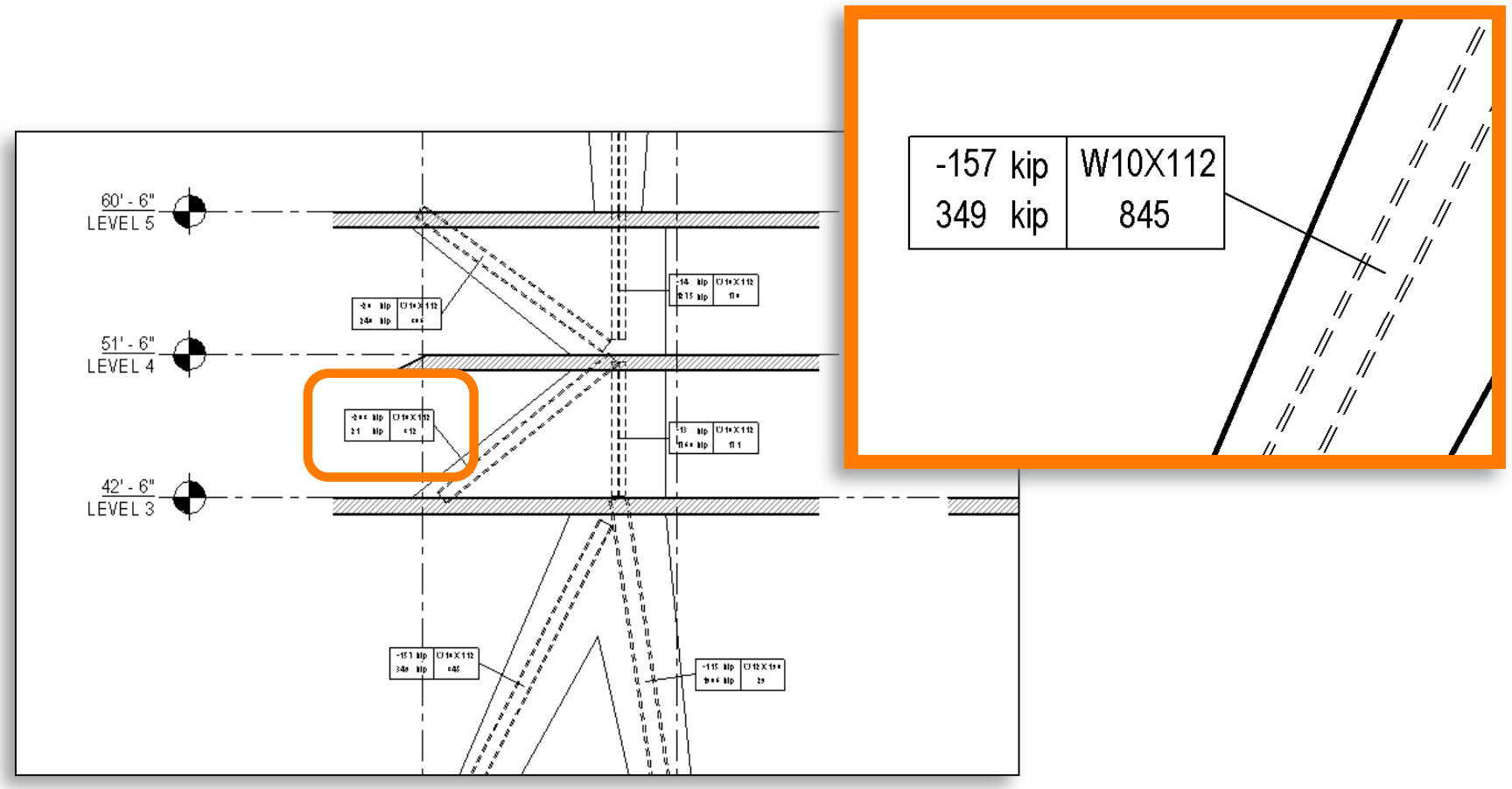
‘Complex’ Geometry – Sloping Columns (!)



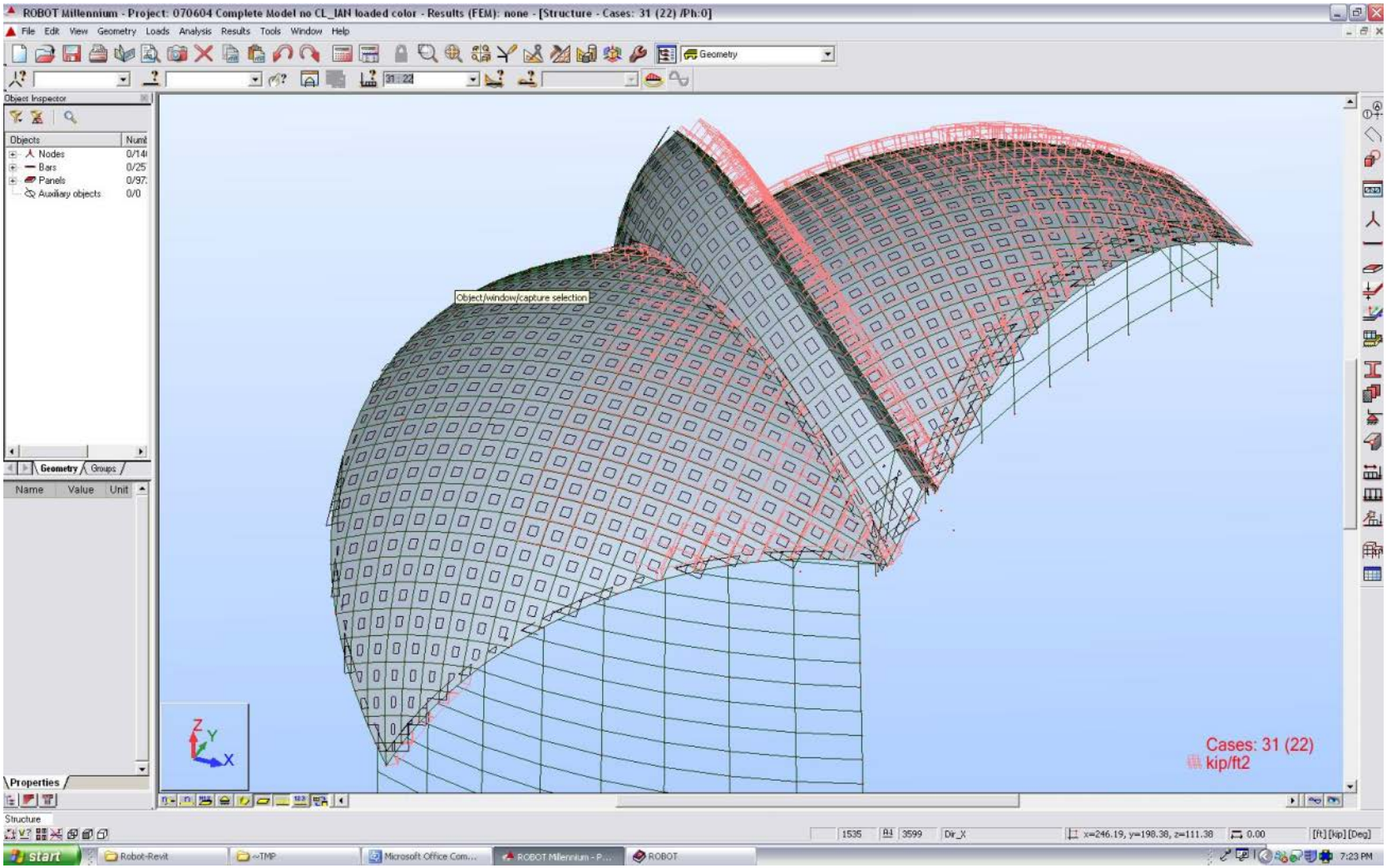

Autodesk Revit Structure 4
File Edit View Modelling Drafting Site Tools Settings Window Help
LR_Ian.rvt - Project browser
Views (Sections As Plans)
Structural Plans
3D Views
3D Full Analytical
3D Full Render
CORE
FOUNDATIONS
ISO Column A
ISO Column B
LEVEL 1 RAMPS
Stair
{3D}
Elevations (Building Elevation)
Sections (Building Section)
Drafting Views (Detail)
Graphical Column Schedules
Legends
Schedules/Quantities
DRAWING LIST
Structural Connection Schedule
Structural Foundation Schedule
Structural Foundation Schedule 2
Structural Foundation Schedule 3
STRUCTURAL FRAMING SCHEI
VIEW LIST
Sheets (all)
Families
Groups
LR_Ian.rvt - 3D View: 3D Full Render
LR_Ian.rvt - Schedule: STRUCTURAL FRAMING SCHEDULE
STRUCTURAL FRAMING SCHEDULE
BAR_ID TYPE LENGTH WEIGHT COMPRESSION TENSION
25 WI10X112 12' - 7" 1386 lb 1288 kip 0 kip
26 WI10X112 15' - 9 1/2" 1743 lb 1222 kip 0 kip
27 WI10X112 13' - 7 1/2" 1481 lb 921 kip 0 kip
28 WI10X112 9' - 0" 978 lb 571 kip 0 kip
29 WI12X190 24' - 9 1/2" 1928 kip 0 kip
30 WI12X190 26' - 4 1/2" 1684 kip 0 kip
31 WI12X190 15' - 6 1/2" 1635 kip 0 kip
32 WI12X190 11' - 4" 1756 kip 0 kip
34 WI12X305 28' - 1 1/2" 7636 lb 2305 kip 0 kip
35 WI10X112 10' - 3 1/2" 1062 lb 1339 kip 0 kip
36 WI10X112 23' - 10 1/2" 2646 lb 1604 kip 0 kip
37 WI10X112 27' - 5" 2996 lb 2231 kip 0 kip
38 WI10X112 27' - 5" 2990 lb 2651 kip 0 kip
39 WI10X112 9' - 3" 904 lb 1408 kip 0 kip
40 WI10X112 25' - 2 1/2" 2567 lb 1118 kip 0 kip
41 WI10X112 25' - 5" 2591 lb 1007 kip 0 kip
42 WI10X112 25' - 1 1/2" 2559 lb 1397 kip 0 kip
43 WI10X112 25' - 4" 2584 lb 919 kip 0 kip
44 WI12X305 9' - 0" 2722 lb 1319 kip -104 kip
45 WI12X190 7 1/2" 1518 kip 0 kip
46 WI10X112 8' - 8" 849 lb 965 kip 0 kip
47 WI10X112 13' - 11" 1535 lb 746 kip 0 kip
48 WI10X112 20' - 0" 1975 lb 445 kip -99 kip
49 WI10X112 9' - 6" 1002 lb 598 kip 0 kip
50 WI10X112 12' - 8" 1386 lb 203 kip 0 kip
51 WI10X112 12' - 8" 1386 lb 99 kip 0 kip
52 WI10X112 10' - 7" 1028 lb 177 kip 0 kip
53 WI10X112 9' - 6" 1003 lb 975 kip 0 kip
54 WI10X112 9' - 1 1/2" 893 lb 727 kip 0 kip
55 WI10X112 9' - 6" 1003 lb 1023 kip 0 kip
56 WI10X112 20' - 0" 2226 lb 432 kip 0 kip
57 WI10X112 8' - 10" 967 lb 1414 kip 0 kip
58 WI10X112 15' - 3 1/2" 1613 lb 1053 kip 0 kip
59 WI10X112 10' - 3 1/2" 1073 lb 1104 kip 0 kip
60 WI10X112 20' - 0" 2226 lb 307 kip 0 kip
61 WI10X112 9' - 7 1/2" 1014 lb 1355 kip 0 kip
62 WI10X112 10' - 3 1/2" 1073 lb 1074 kip 0 kip
63 WI10X112 12' - 4" 1337 lb 1205 kip 0 kip
64 WI12X190 14' - 2 1/2" 1449 kip 0 kip
65 WI12X190 13' - 2" 1845 kip 0 kip
67 WI10X112 10' - 2" 1124 lb 1257 kip 0 kip
68 WI12X190 8' - 10" 2091 kip 0 kip
69 WI12X190 15' - 8" 2142 kip 0 kip
70 WI12X190 20' - 2" 1465 kip 0 kip
71 WI10X112 4' - 4" 473 lb 1355 kip 0 kip
72 WI10X112 5' - 0 1/2" 552 lb 858 kip 0 kip
73 WI10X112 17' - 5 1/2" 1934 lb 749 kip 0 kip
75 WI12X190 8' - 4 1/2" 2354 kip 0 kip
76 WI12X190 7 1/2" 2180 kip 0 kip
Ready
Start
REVISED TAGS 070122
2007 Resourcing
LR API Examples
Inbox - Microsoft Outlook
SourceForge.net: Downl...
Autodesk Revit Struc...
4:28 PM

	A	B	C	D	E	F	G	H
4								
5		Robot Analysis Output-Member Forces						
6		Bar	Comp (kips)	Tension (kips)	Section	Length	Axial Comp @E pass W10x11	
7		1	**1217**	**-5**	W 10x112	9	Pass	
8		2	**996**	**-6**	W 10x112	9	Pass	
9		3	**652**	**-2**	W 10x112	23	Pass	
10		4	**1031**	**-6**	W 10x112	9	Pass	
11		5	**868**	**-3**	W 10x112	9	Pass	
12		6	**536**	**-1**	W 10x112	23	Pass	
13		7	**446**	**-9**	W 10x112	9	Pass	
14		8	**467**	**-3**	W 10x112	9	Pass	
15		9	**325**	**-38**	W 10x112	27	Pass	
16		10	**390**	**-38**	W 10x112	19	Pass	
17		11	**1400**	**-45**	W 10x112	12	NG	
18		12	**979**	**-45**	W 10x112	20	Pass	
19		13	**604**	**-53**	W 10x112	25	Pass	
20		14	**341**	**-9**	W 10x112	21	Pass	
21		15	**216**	**-2**	W 10x112	23	Pass	
22		16	**669**	**-1668**	W 12x305	24	Pass	
23		17	**583**	**-1**	W 10x112	33	Pass	
24		18	**472**	**-10**	W 10x112	33	Pass	
25		19	**98**	**-538**	W 10x112	12	Pass	
26		20	**795**	**-89**	W 10x112	11	Pass	
27		21	**349**	**-1**	W 10x112	13	Pass	
28		22	**169**	**-1**	W 10x112	13	Pass	
29		23	**87**	**-14**	W 10x112	23	Pass	
30		24	**429**	**-9**	W 10x112	9	Pass	
31		25	**1284**	**-45**	W 10x112	13	Pass	
32		26	**1268**	**-69**	W 10x112	16	Pass	
33		27	**964**	**-8**	W 10x112	14	Pass	Pass
34		28	**548**	**-14**	W 10x112	9	Pass	Pass
35		**29**	**1906**	**-115**	**W 12x190**	25	NG	Pass
36		**30**	**1708**	**-33**	**W 12x190**	26	NG	Pass
37		**31**	**1675**	**-10**	**W 12x190**	16	NG	Pass
38		**32**	**1782**	**-4**	**W 12x190**	11	NG	Pass




60' - 6"
LEVEL 5
51' - 6"
LEVEL 4
42' - 6"
LEVEL 3
-157 kip
349 kip
W10X112
845

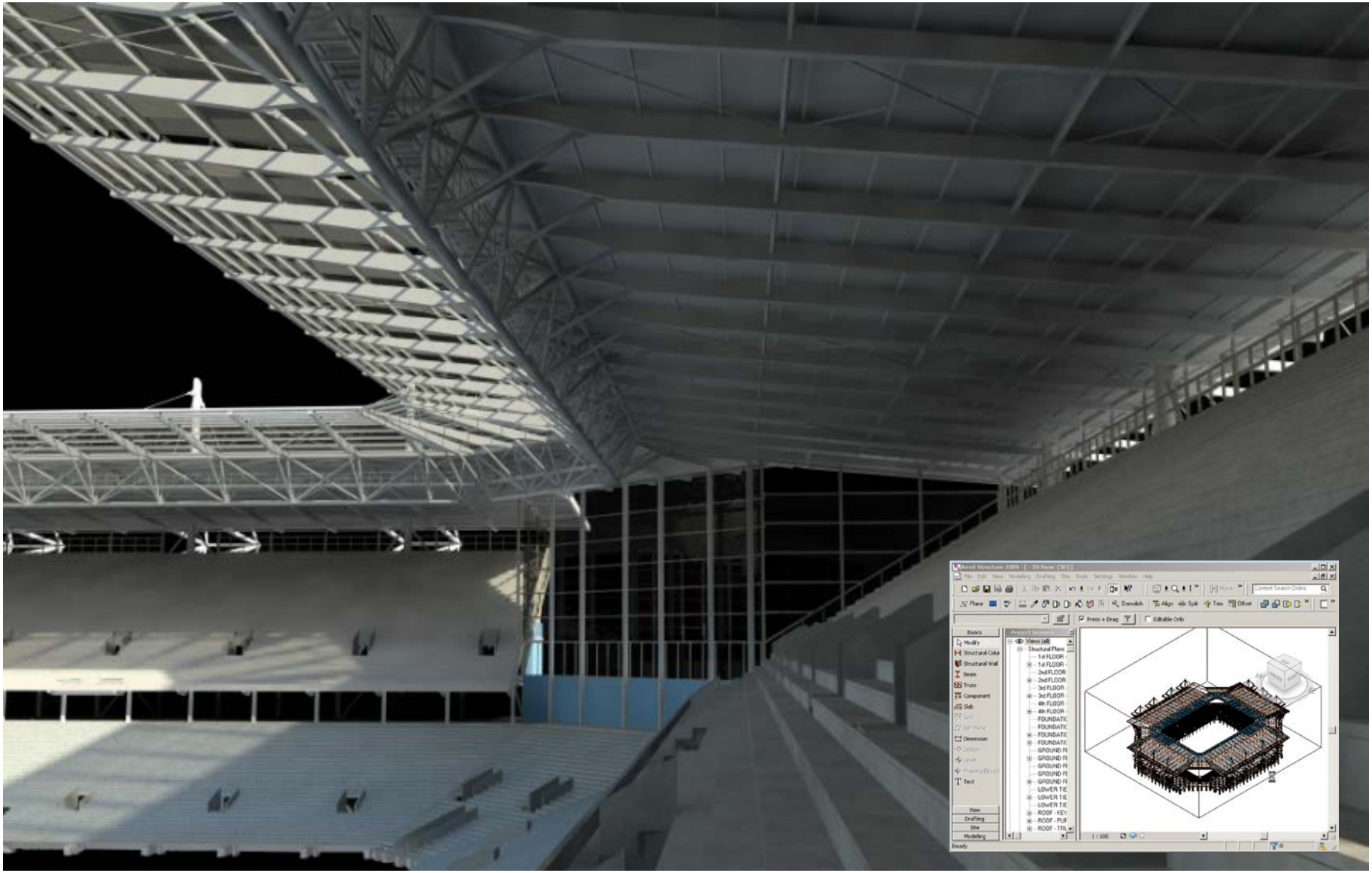
Linking Wind Data



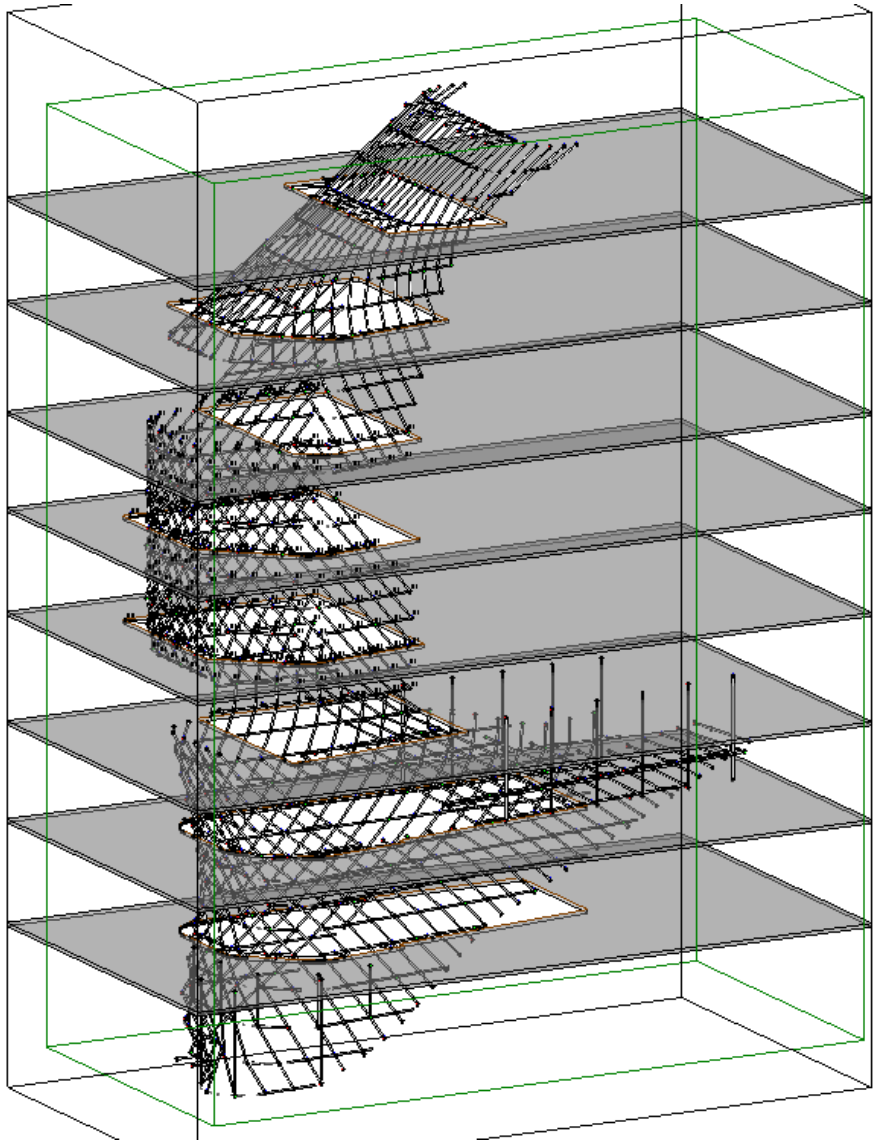
Element Design Automation

Engineering Complex Geometry Structures

Buro Happold



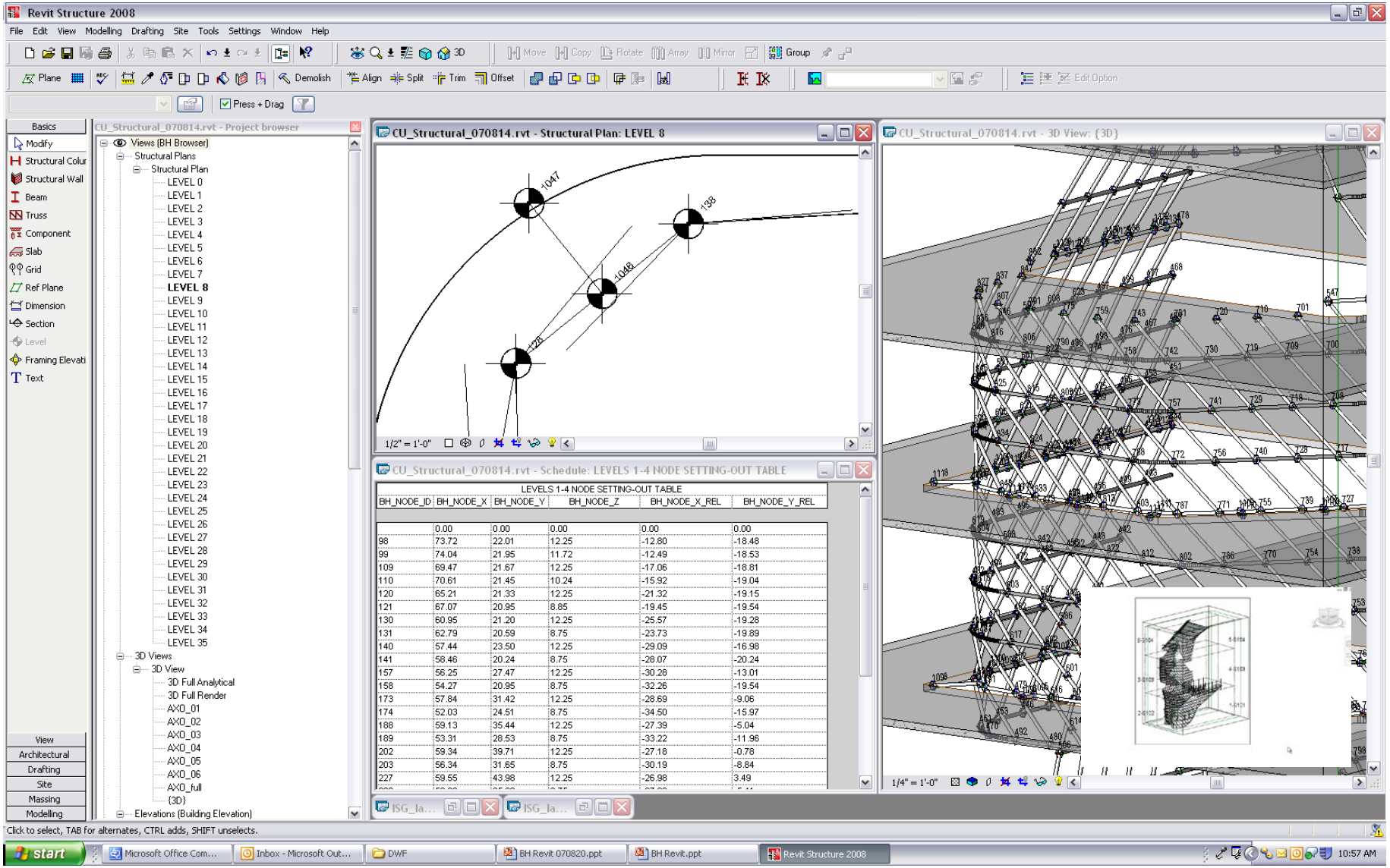
Integration of Complex and Simple Structures



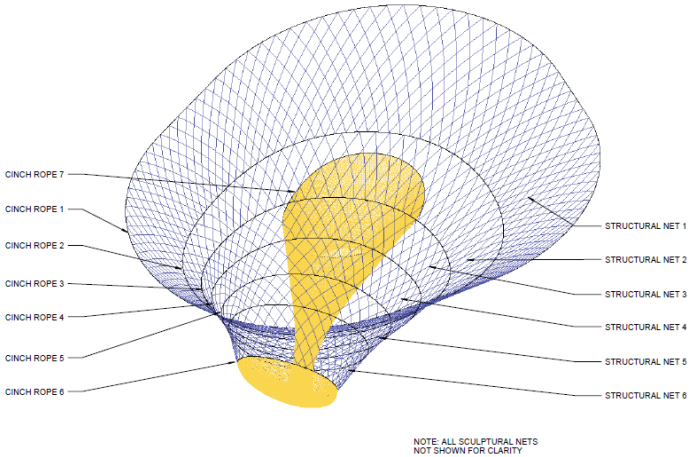
Integration of Complex and Simple Structures

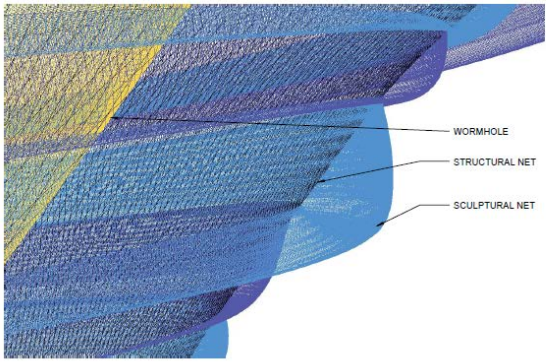
Engineering Complex Geometry Structures

Buro Happold

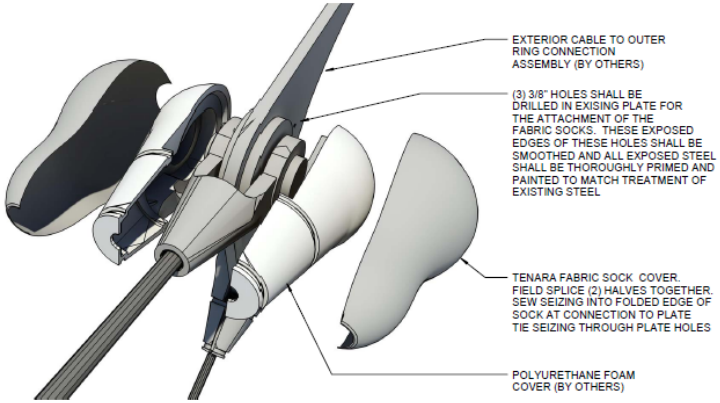


- **Linking Buro in house analysis software (Tensyl) with Revit**

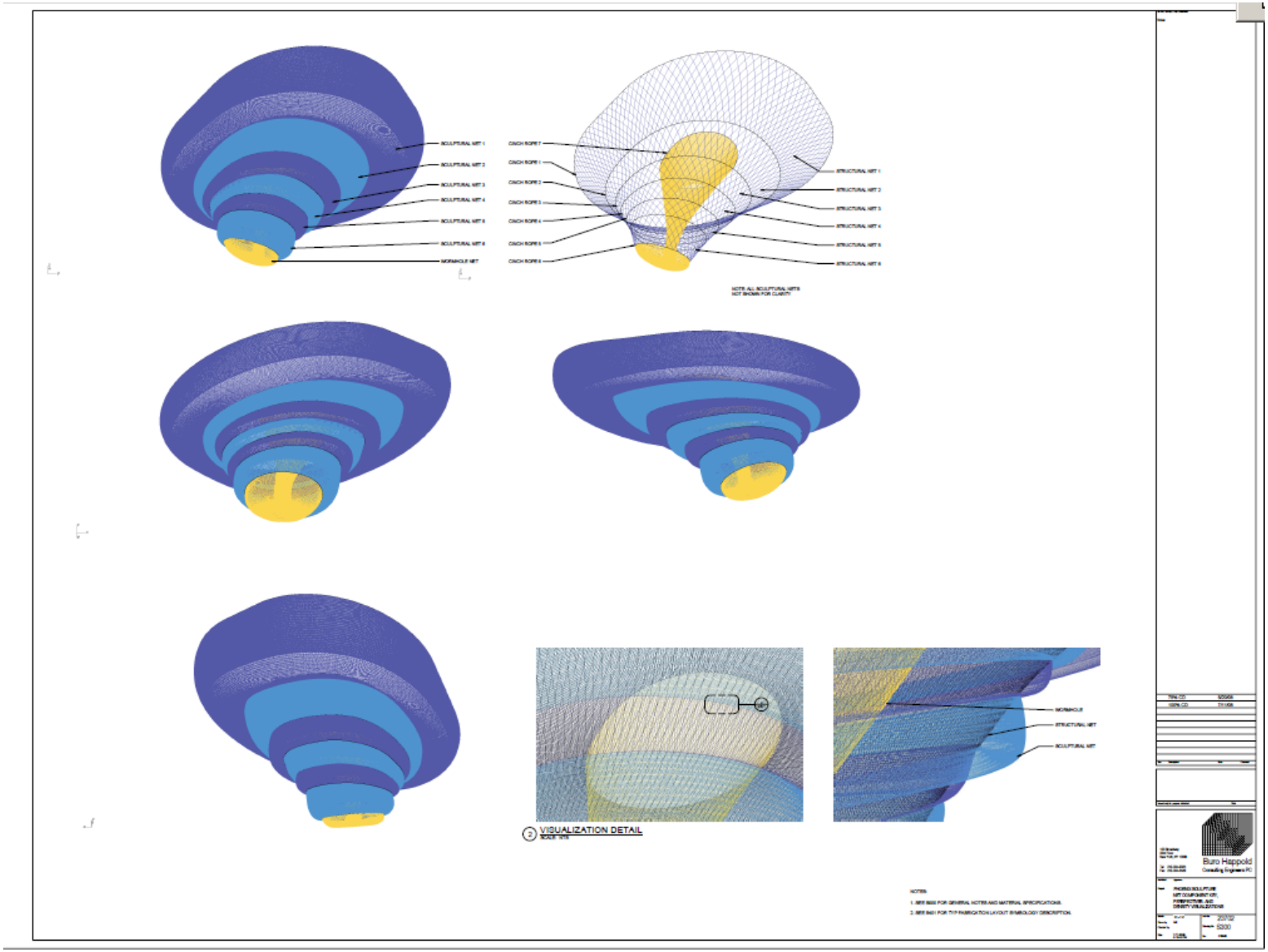




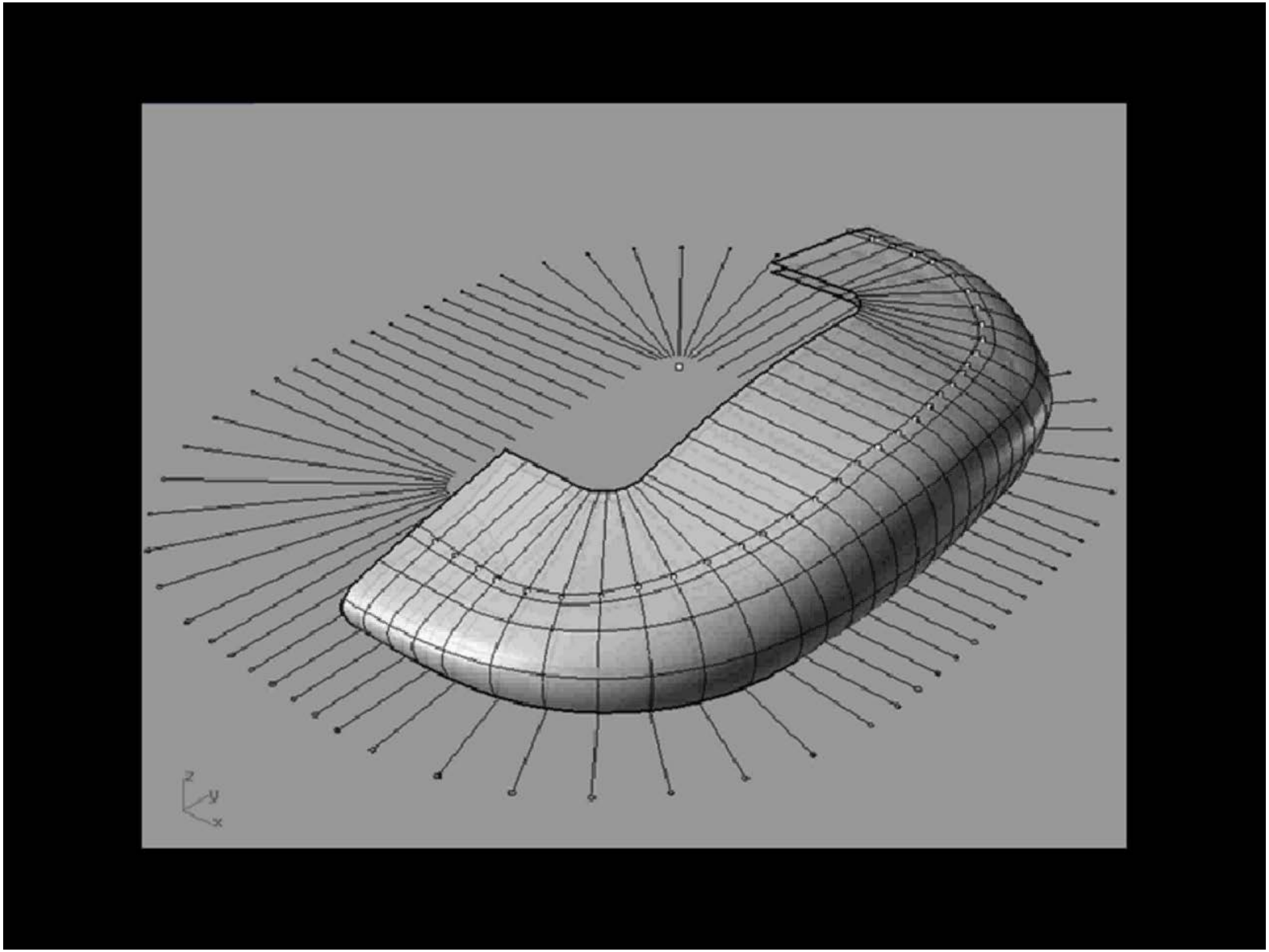
53L	1' - 11 1/4"	1' - 9 7/8"	1' - 9"	1' - 7 7/8"
54L	1' - 10 1/8"	1' - 8 7/8"	1' - 8 1/8"	1' - 7"
55L	1' - 9 1/8"	1' - 8"	1' - 7 1/4"	1' - 6 1/4"
56L	1' - 8 1/8"	1' - 7 1/8"	1' - 6 1/2"	2' - 2 1/8"
57L	1' - 7 3/8"	2' - 4 1/8"	2' - 2 5/8"	2' - 0 5/8"
58L	2' - 4 5/8"	2' - 2 1/2"	2' - 1 1/8"	1' - 11 3/4"
59L	2' - 3"	2' - 1 1/2"	2' - 0 3/8"	1' - 11 1/2"
60L	2' - 2"	2' - 1 1/8"	2' - 0 1/8"	1' - 11 5/8"
61L	2' - 1 3/4"	2' - 1 1/4"	2' - 0 1/4"	1' - 4"
62L	2' - 1 7/8"	1' - 4 1/2"	1' - 4 1/4"	1' - 4 3/8"
63L	1' - 4 3/4"	1' - 4 3/4"	1' - 4 5/8"	1' - 4 3/4"
64L	1' - 5"	1' - 5 1/8"	1' - 4 7/8"	1' - 5 1/8"
65L	1' - 5 3/8"	1' - 5 1/2"	1' - 5 1/2"	1' - 5 3/4"
66L	1' - 5 7/8"	1' - 6 1/8"	1' - 6"	1' - 6 3/8"
67L	1' - 6 3/8"	1' - 6 3/4"	1' - 6 3/4"	1' - 7 1/4"
68L	1' - 7 1/8"	1' - 7 1/2"	1' - 7 5/8"	1' - 8 1/4"
69L	1' - 7 7/8"	1' - 8 1/2"	3' - 7 3/8"	



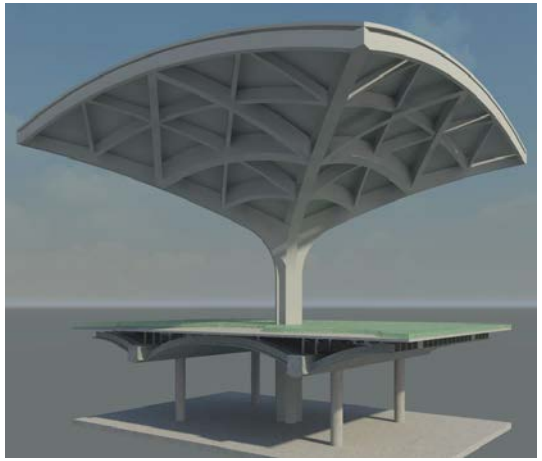
Geometry Automation

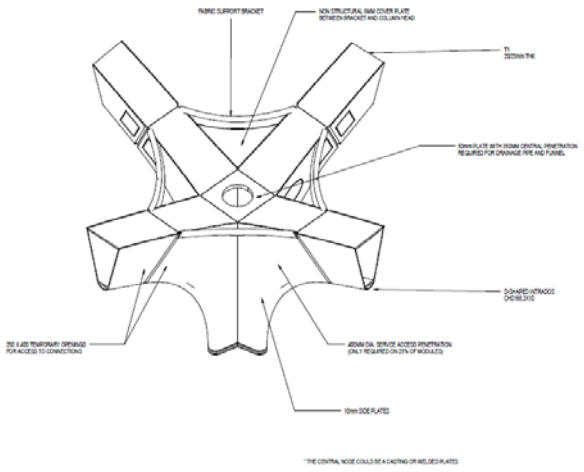


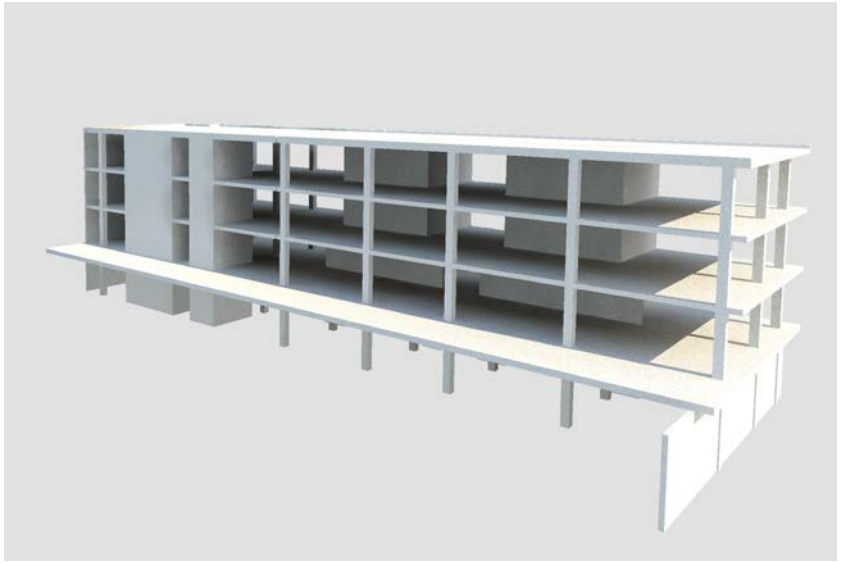
Geometry Automation

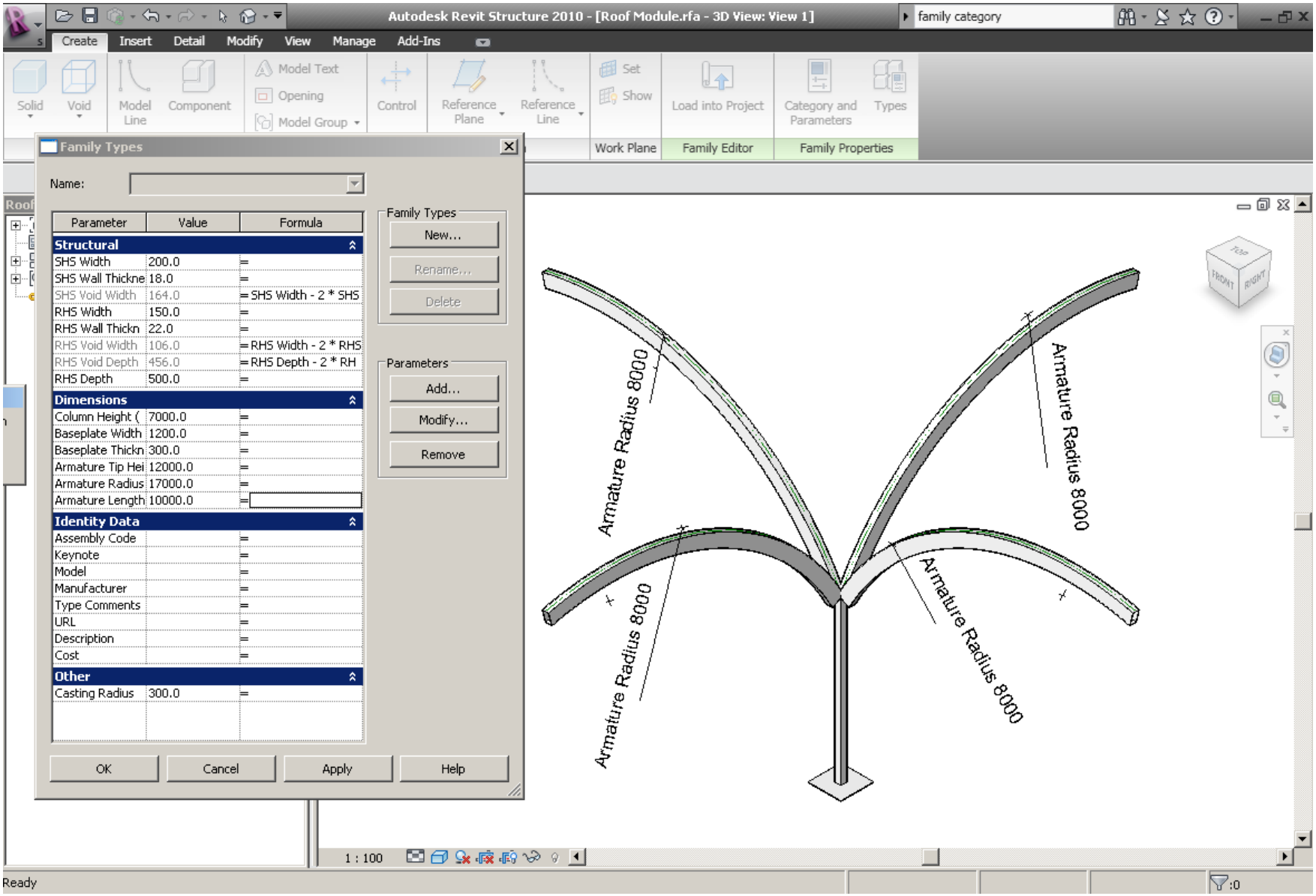


Modular and Component Building Design



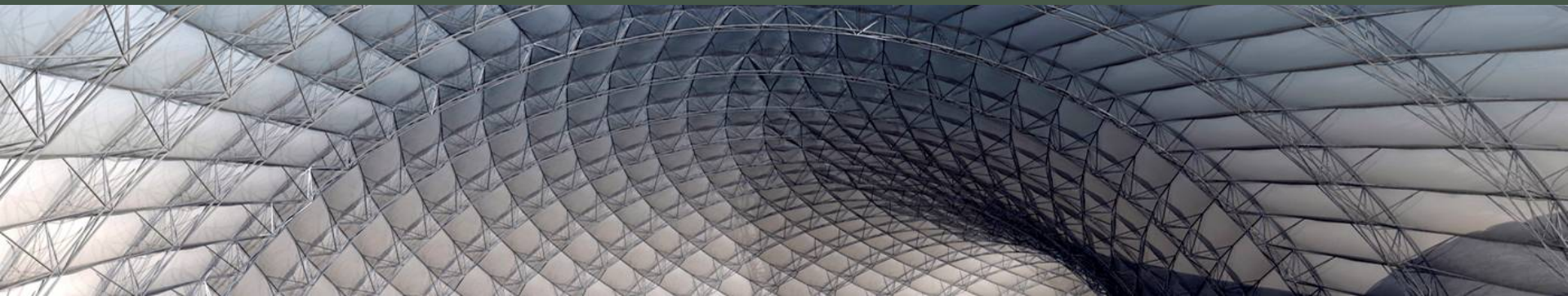





Autodesk Revit Structure 2010 - [Roof Module.rfa - 3D View: View 1]
family category
Create
Insert
Detail
Modify
View
Manage
Add-Ins
Solid
Void
Model Line
Component
Model Text
Opening
Model Group
Control
Reference Plane
Reference Line
Set
Show
Load into Project
Category and Parameters
Types
Work Plane
Family Editor
Family Properties
Family Types
Name:
Parameter
Value
Formula
Structural
SHS Width 200.0 =
SHS Wall Thickne 18.0 =
SHS Void Width 164.0 = SHS Width - 2 * SHS
RHS Width 150.0 =
RHS Wall Thickn 22.0 =
RHS Void Width 106.0 = RHS Width - 2 * RHS
RHS Void Depth 456.0 = RHS Depth - 2 * RH
RHS Depth 500.0 =
Dimensions
Column Height (7000.0 =
Baseplate Width 1200.0 =
Baseplate Thickn 300.0 =
Armature Tip Hei 12000.0 =
Armature Radius 17000.0 =
Armature Length 10000.0 =
Identity Data
Assembly Code =
Keynote =
Model =
Manufacturer =
Type Comments =
URL =
Description =
Cost =
Other
Casting Radius 300.0 =
Family Types
New...
Rename...
Delete
Parameters
Add...
Modify...
Remove
OK
Cancel
Apply
Help
Armature Radius 8000
Armature Radius 8000
Armature Radius 8000
Armature Radius 8000
1 : 100
Ready

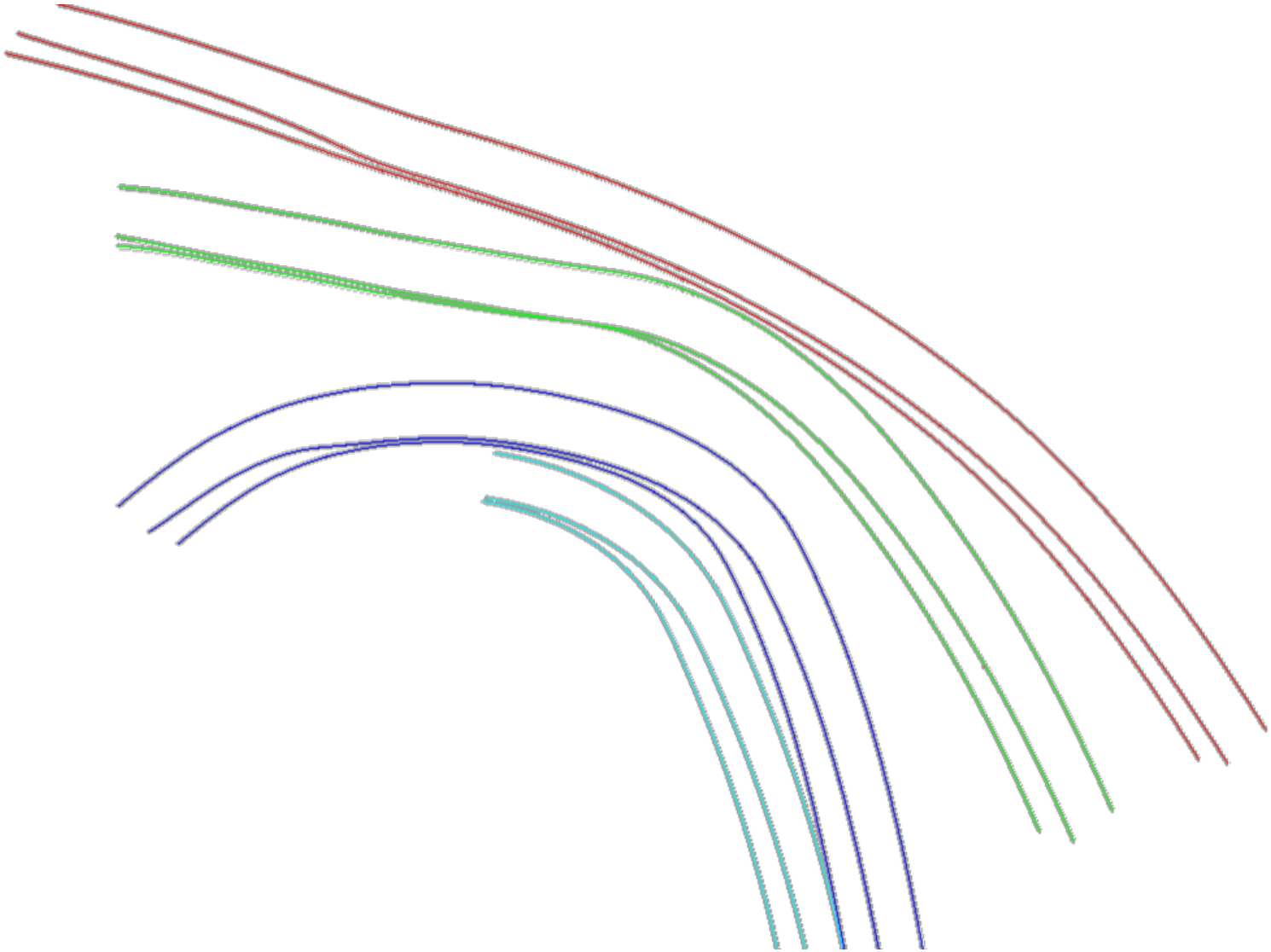
BIM Recent Example

Buro Happold



Buro Happold

Buro Happold



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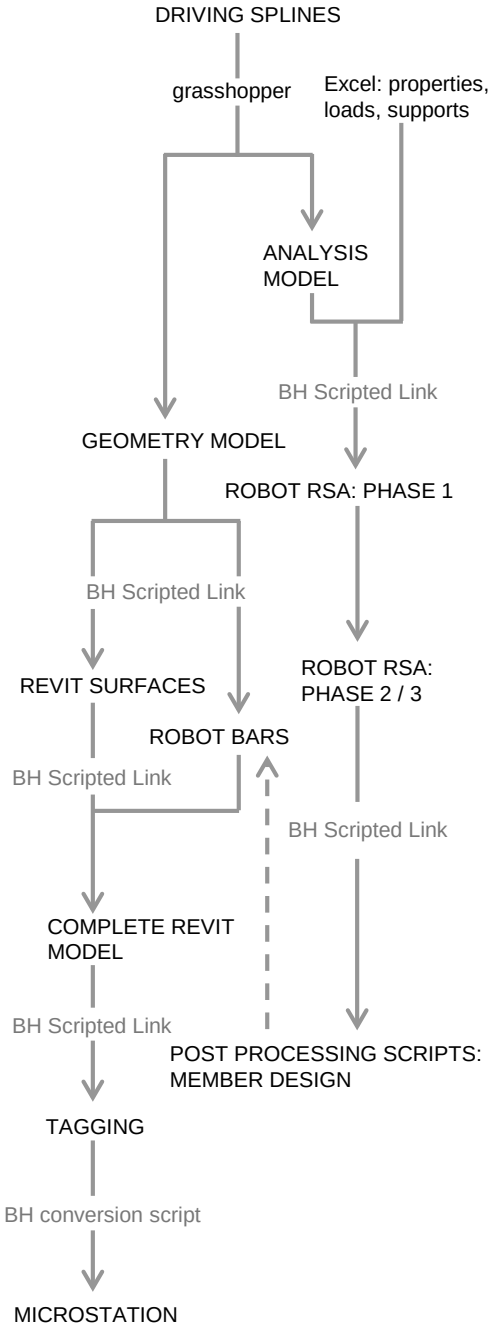


Buro Happold

DRIVING SPLINES

grasshopper

Excel: properties, loads, supports

ANALYSIS MODEL

BH Scripted Link

GEOMETRY MODEL

ROBOT RSA: PHASE 1

BH Scripted Link

REVIT SURFACES

ROBOT RSA: PHASE 2 / 3

ROBOT BARS

BH Scripted Link

BH Scripted Link

COMPLETE REVIT MODEL

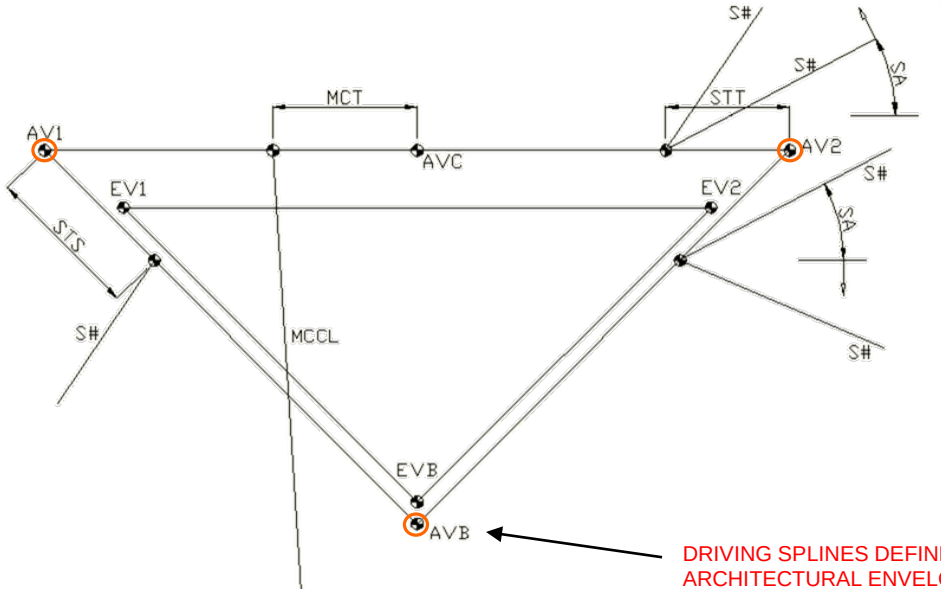
BH Scripted Link

POST PROCESSING SCRIPTS: MEMBER DESIGN

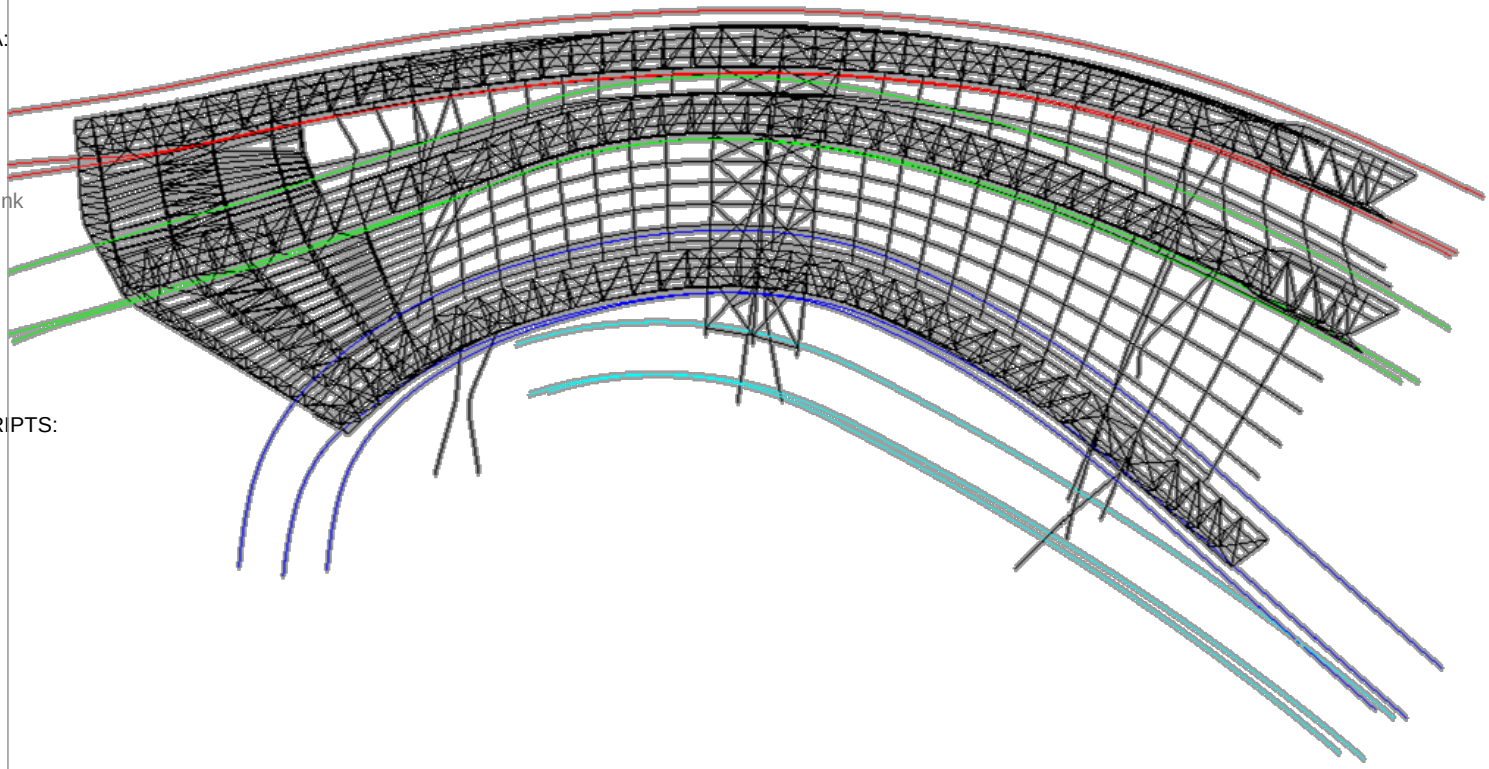
TAGGING

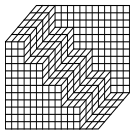
BH conversion script

MICROSTATION



DRIVING SPLINES DEFINE ARCHITECTURAL ENVELOPE





Buro Happold

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grasshopper

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BH Scripted Link

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ROBOT RSA: PHASE 1

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BH Scripted Link

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BH Scripted Link

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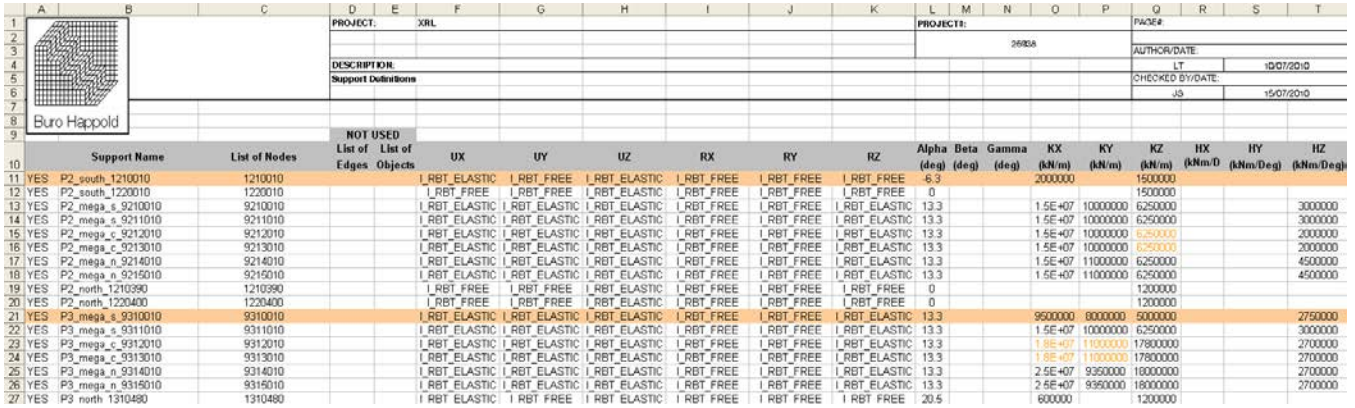

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				DESCRIPTION:														LT		10/07/2010	
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																		JG		15/07/2010	
	Buro Happold																				
				NOT USED																	
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YES	P2_south_1210010	1210010				I_RBT_ELASTIC	I_RBT_FREE	I_RBT_ELASTIC	I_RBT_FREE	I_RBT_FREE	I_RBT_FREE	-6.3			2000000		1500000				
YES	P2_south_1220010	1220010				I_RBT_FREE	I_RBT_FREE	I_RBT_ELASTIC	I_RBT_FREE	I_RBT_FREE	I_RBT_FREE	0					1500000				
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YES	P2_mega_c_9213010	9213010				I_RBT_ELASTIC	I_RBT_ELASTIC	I_RBT_ELASTIC	I_RBT_FREE	I_RBT_FREE	I_RBT_ELASTIC	13.3			1.5E+07	10000000	6250000				2000000
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YES	P2_mega_n_9215010	9215010				I_RBT_ELASTIC	I_RBT_ELASTIC	I_RBT_ELASTIC	I_RBT_FREE	I_RBT_FREE	I_RBT_ELASTIC	13.3			1.5E+07	11000000	6250000				4500000
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YES	P3_mega_s_9311010	9311010				I_RBT_ELASTIC	I_RBT_ELASTIC	I_RBT_ELASTIC	I_RBT_FREE	I_RBT_FREE	I_RBT_ELASTIC	13.3			1.5E+07	10000000	6250000				3000000
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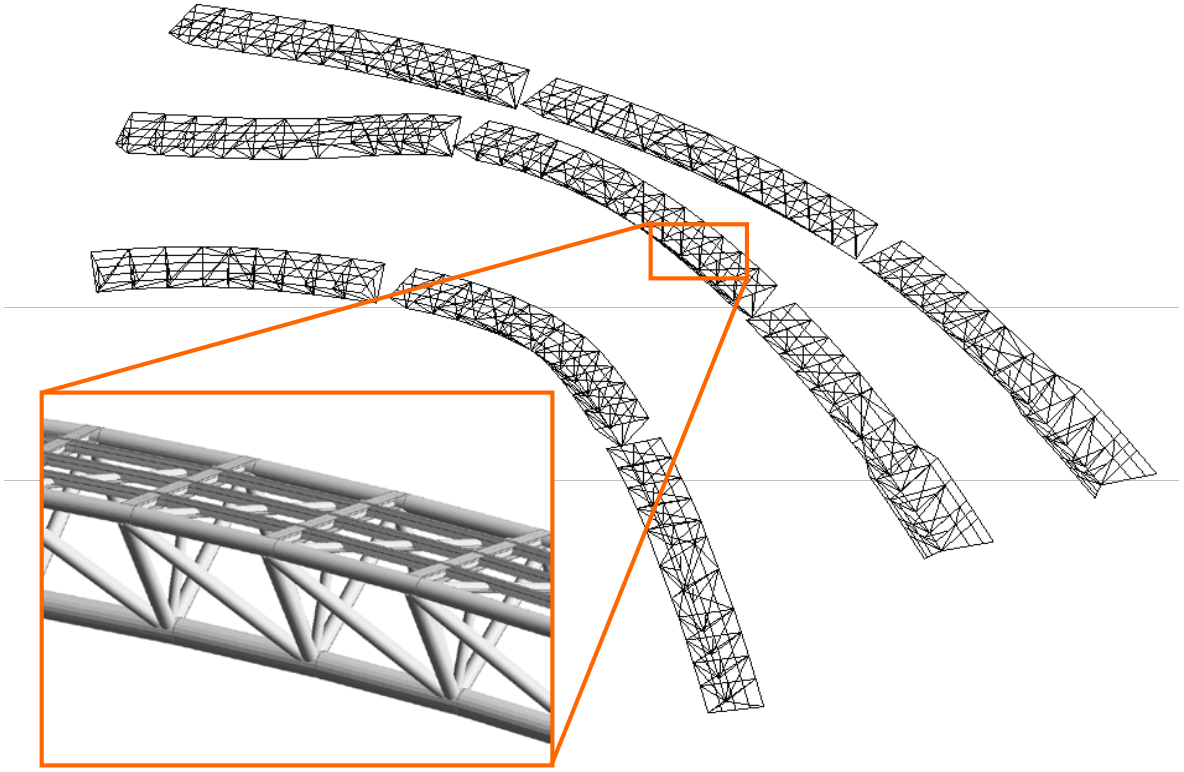
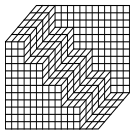
YES	P3_mega_n_9315010	9315010				I_RBT_ELASTIC	I_RBT_ELASTIC	I_RBT_ELASTIC	I_RBT_FREE	I_RBT_FREE	I_RBT_ELASTIC	13.3			2.5E+07	9360000	18000000				2700000
YES	P3_north_1310480	1310480				I_RBT_ELASTIC	I_RBT_FREE	I_RBT_ELASTIC	I_RBT_FREE	I_RBT_FREE	I_RBT_FREE	20.5			600000		1200000				





Buro Happold

DRIVING SPLINES

grasshopper

Excel: properties, loads, supports

ANALYSIS MODEL

BH Scripted Link

GEOMETRY MODEL

ROBOT RSA: PHASE 1

BH Scripted Link

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ROBOT RSA: PHASE 2 / 3

ROBOT BARS

BH Scripted Link

BH Scripted Link

COMPLETE REVIT MODEL

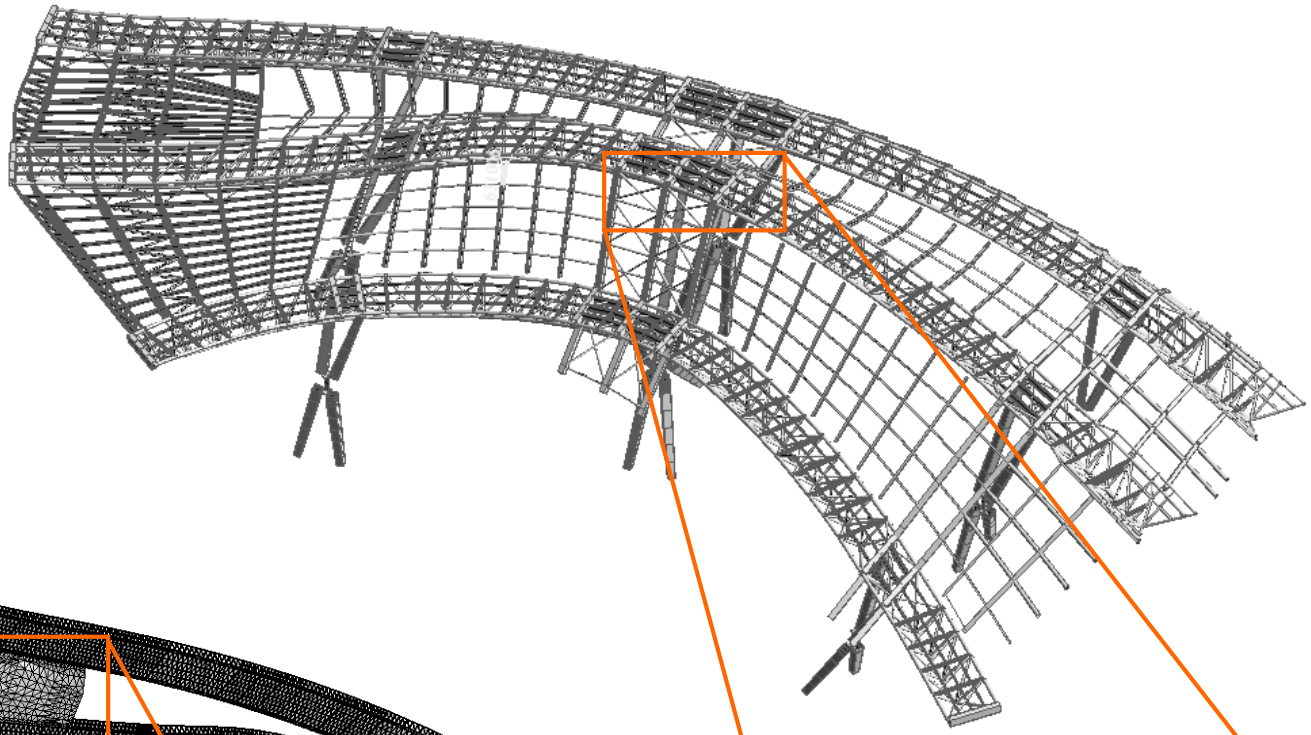
BH Scripted Link

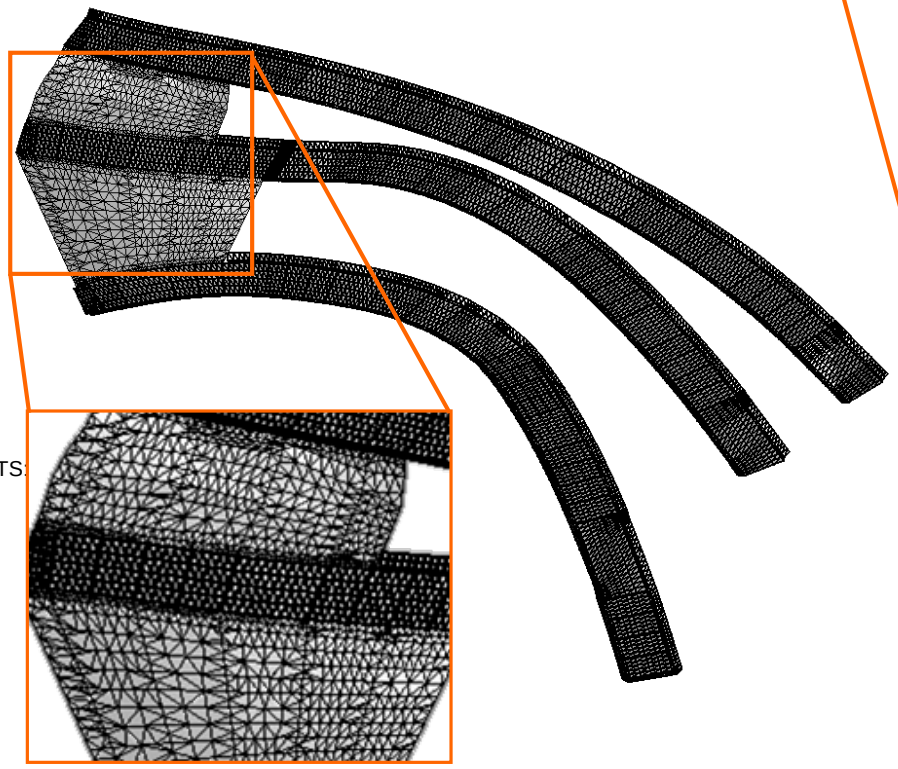
POST PROCESSING SCRIPTS: MEMBER DESIGN

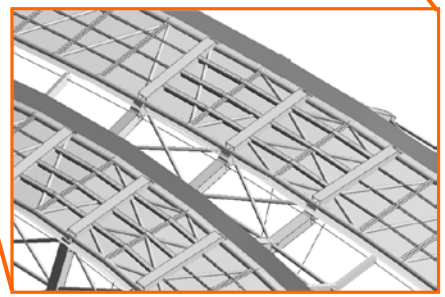
TAGGING

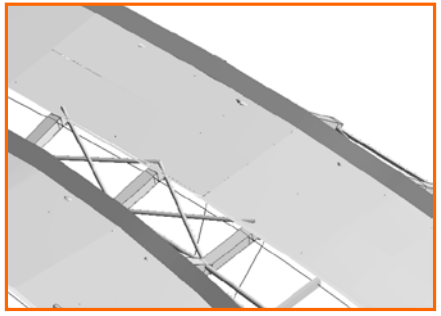
BH conversion script

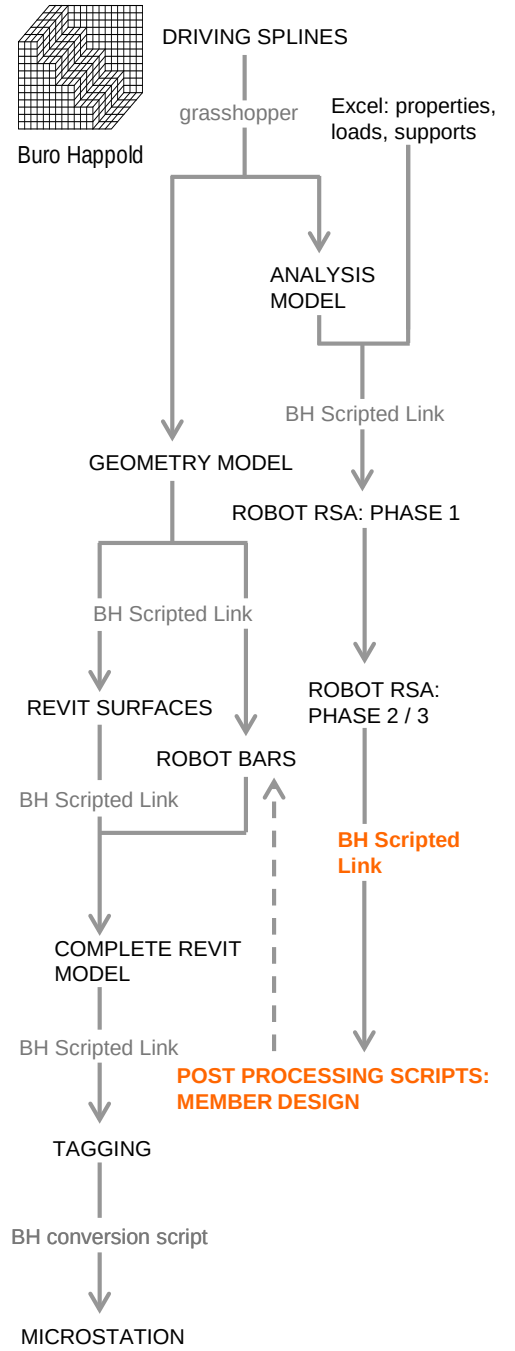
MICROSTATION

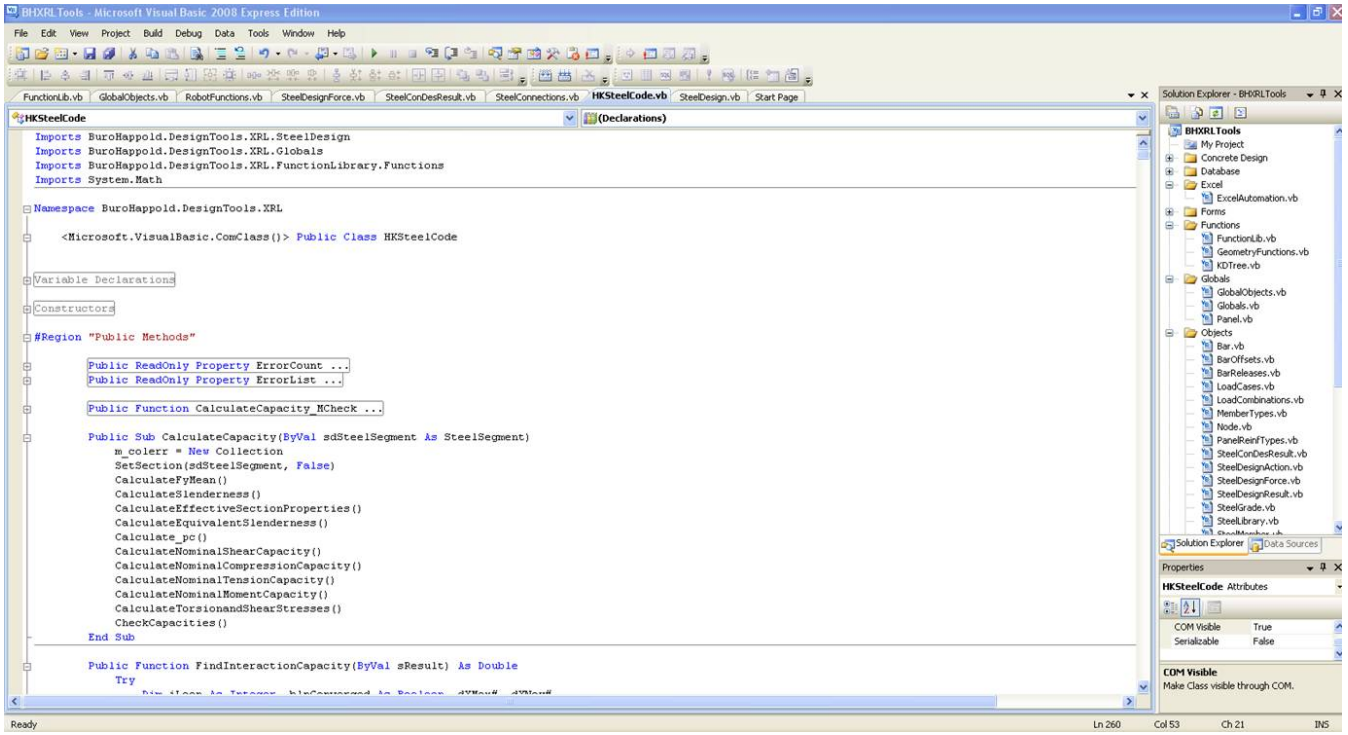


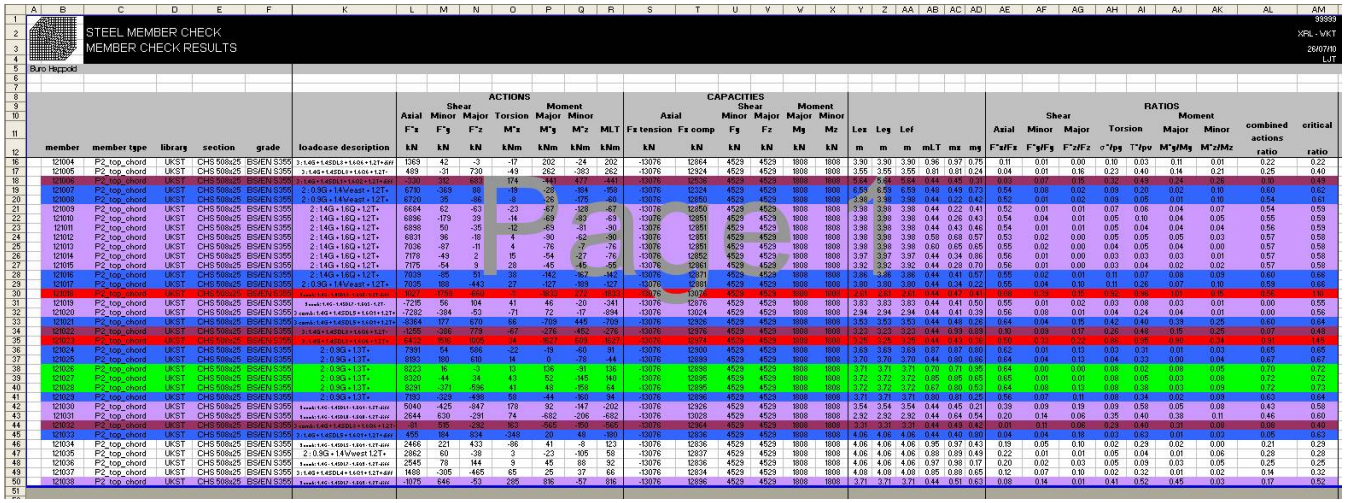







DRIVING SPLINES
grasshopper
Excel: properties, loads, supports
Buro Happold
ANALYSIS MODEL
BH Scripted Link
GEOMETRY MODEL
ROBOT RSA: PHASE 1
BH Scripted Link
REVIT SURFACES
ROBOT RSA: PHASE 2 / 3
ROBOT BARS
BH Scripted Link
BH Scripted Link
COMPLETE REVIT MODEL
BH Scripted Link
POST PROCESSING SCRIPTS: MEMBER DESIGN
TAGGING
BH conversion script
MICROSTATION


BHXRLTools - Microsoft Visual Basic 2008 Express Edition
HKSteelCode.vb
Imports BuroHappold.DesignTools.XRL.SteelDesign
Imports BuroHappold.DesignTools.XRL.Globals
Imports BuroHappold.DesignTools.XRL.FunctionLibrary.Functions
Imports System.Math
Namespace BuroHappold.DesignTools.XRL
Public Class HKSteelCode
Variable Declarations
Constructors
#Region "Public Methods"
Public ReadOnly Property ErrorCount ...
Public ReadOnly Property ErrorList ...
Public Function CalculateCapacity_MCheck ...
Public Sub CalculateCapacity(ByVal sdSteelSegment As SteelSegment)
m_colerr = New Collection
SetSection(sdSteelSegment, False)
CalculateFyMean()
CalculateSlenderness()
CalculateEffectiveSectionProperties()
CalculateEquivalentSlenderness()
Calculate_pc()
CalculateNominalShearCapacity()
CalculateNominalCompressionCapacity()
CalculateNominalTensionCapacity()
CalculateNominalMomentCapacity()
CalculateTorsionandShearStresses()
CheckCapacities()
End Sub
Public Function FindInteractionCapacity(ByVal sResult) As Double
Try
Solution Explorer - BHXRLTools
BHXRLTools
My Project
Concrete Design
Database
Excel
ExcelAutomation.vb
Forms
Functions
FunctionLib.vb
GeometryFunctions.vb
KDTree.vb
Globals
GlobalObjects.vb
Globals.vb
Panel.vb
Objects
Bar.vb
BarOffsets.vb
BarReleases.vb
LoadCases.vb
LoadCombinations.vb
MemberTypes.vb
Node.vb
PanelReinfTypes.vb
SteelConDesResult.vb
SteelDesignAction.vb
SteelDesignForce.vb
SteelDesignResult.vb
SteelGrade.vb
SteelLibrary.vb
Properties
HKSteelCode Attributes
COM Visible
Make Class visible through COM.
Ready


STEEL MEMBER CHECK
MEMBER CHECK RESULTS
Buro Happold

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DRIVING SPLINES

grasshopper

Excel: properties, loads, supports

ANALYSIS MODEL

BH Scripted Link

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ROBOT RSA: PHASE 2 / 3

ROBOT BARS

BH Scripted Link

BH Scripted Link

COMPLETE REVIT MODEL

BH Scripted Link

POST PROCESSING SCRIPTS MEMBER DESIGN

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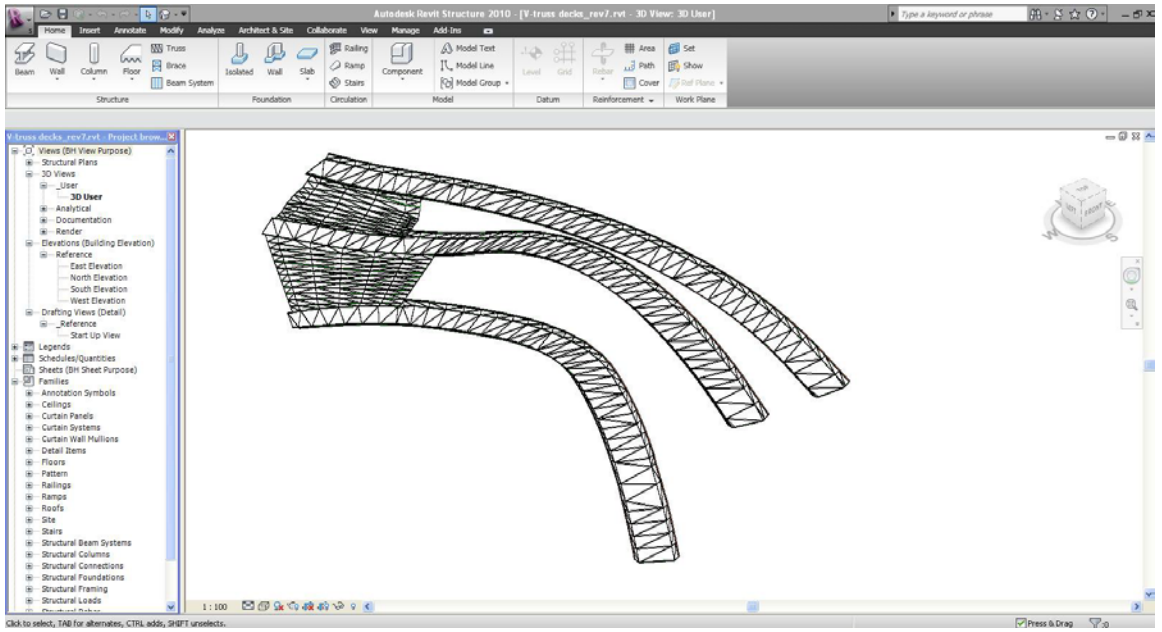
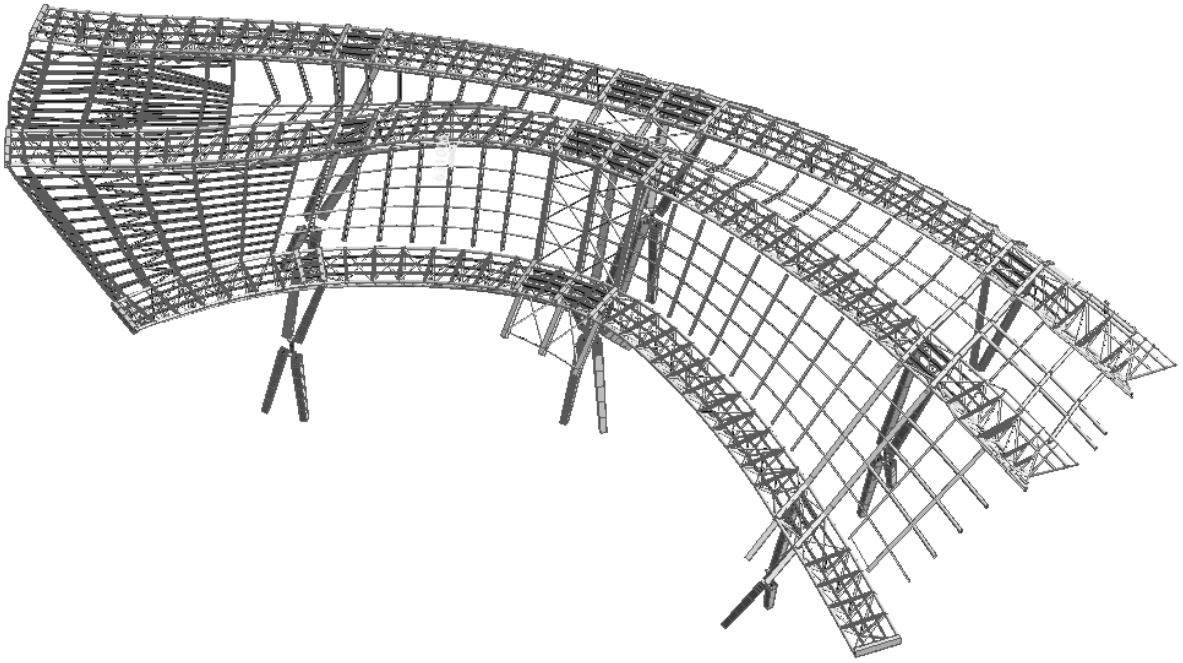
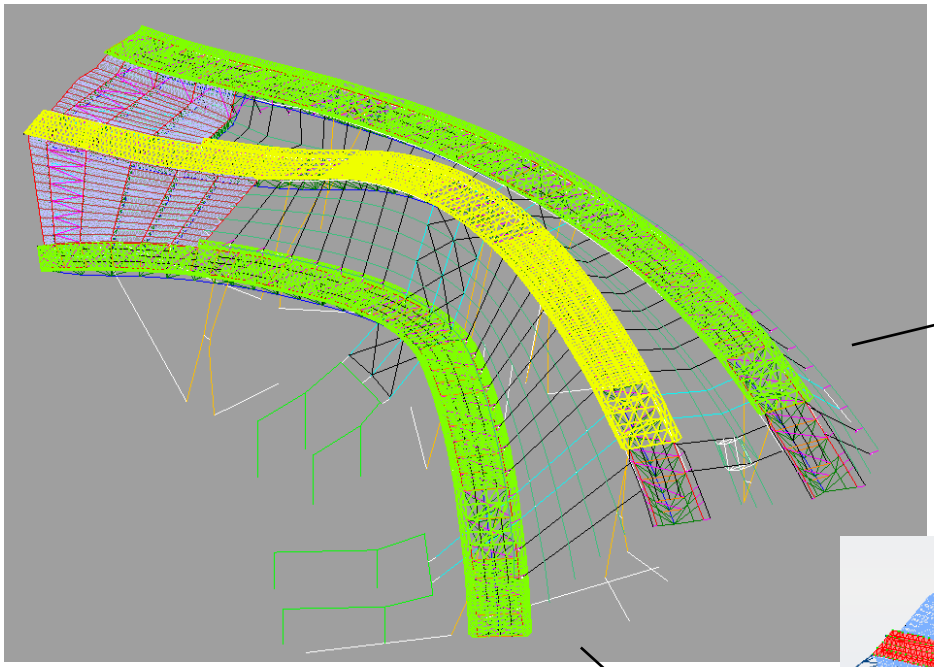
BH conversion script

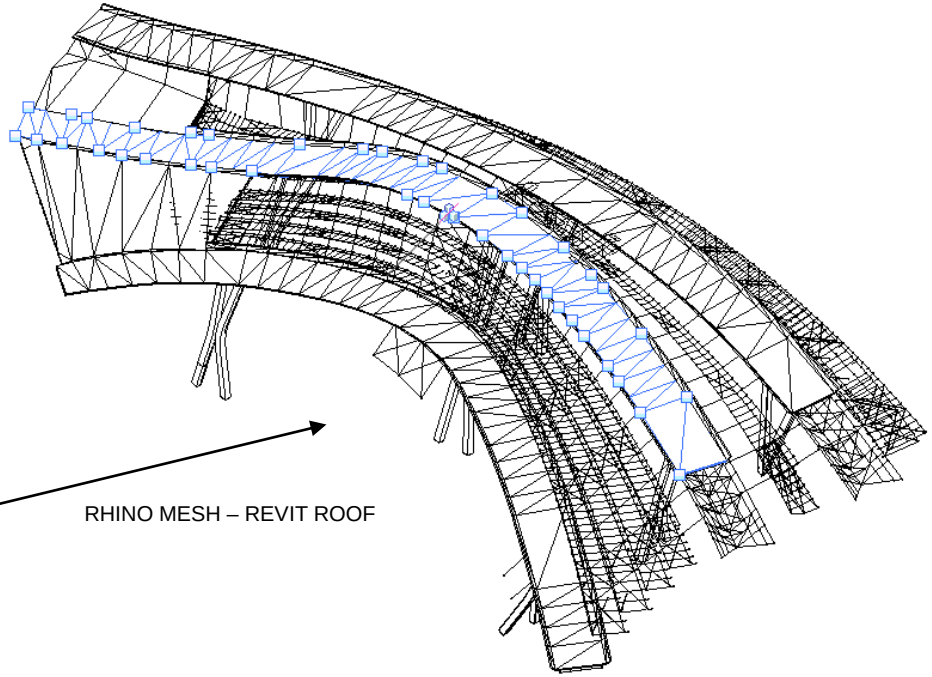
MICROSTATION





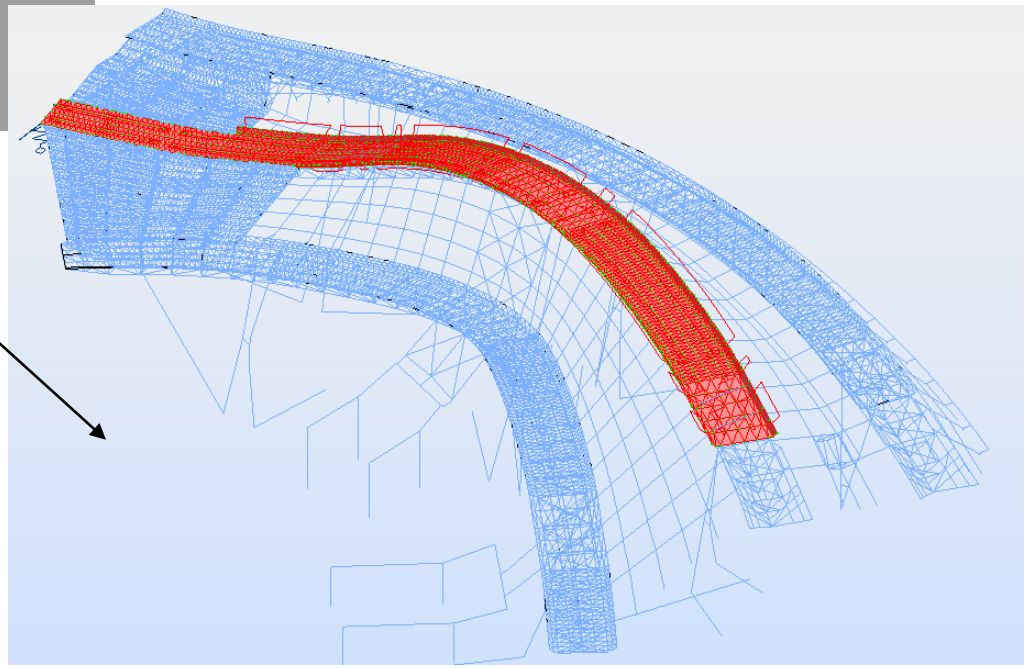
Buro Happold

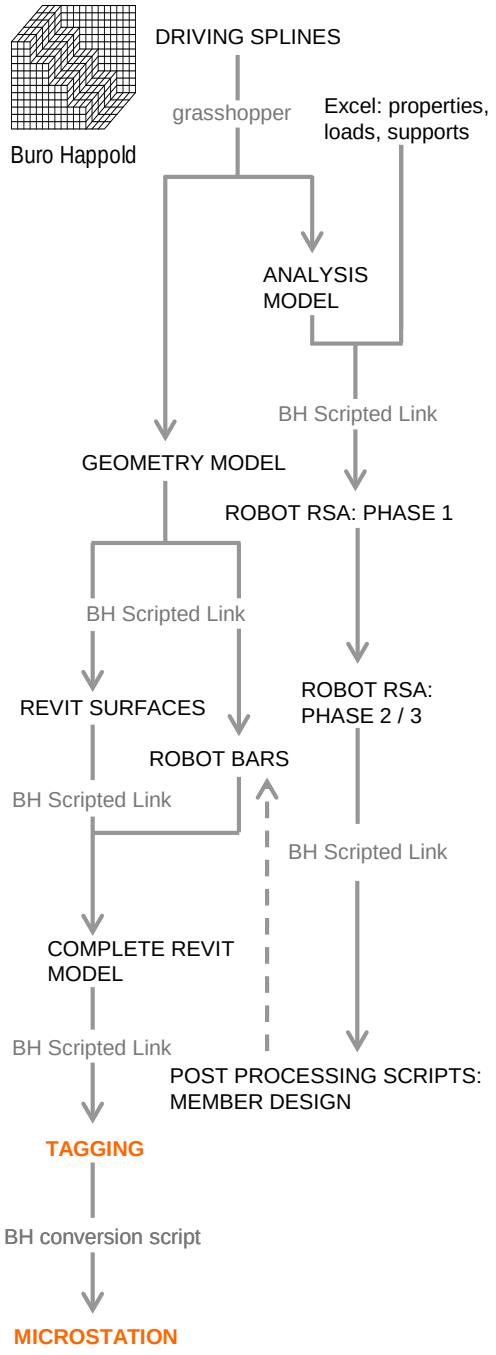




RHINO MESH – REVIT ROOF

RHINO MESH – ROBOT MESH




DRIVING SPLINES
grasshopper
Excel: properties, loads, supports
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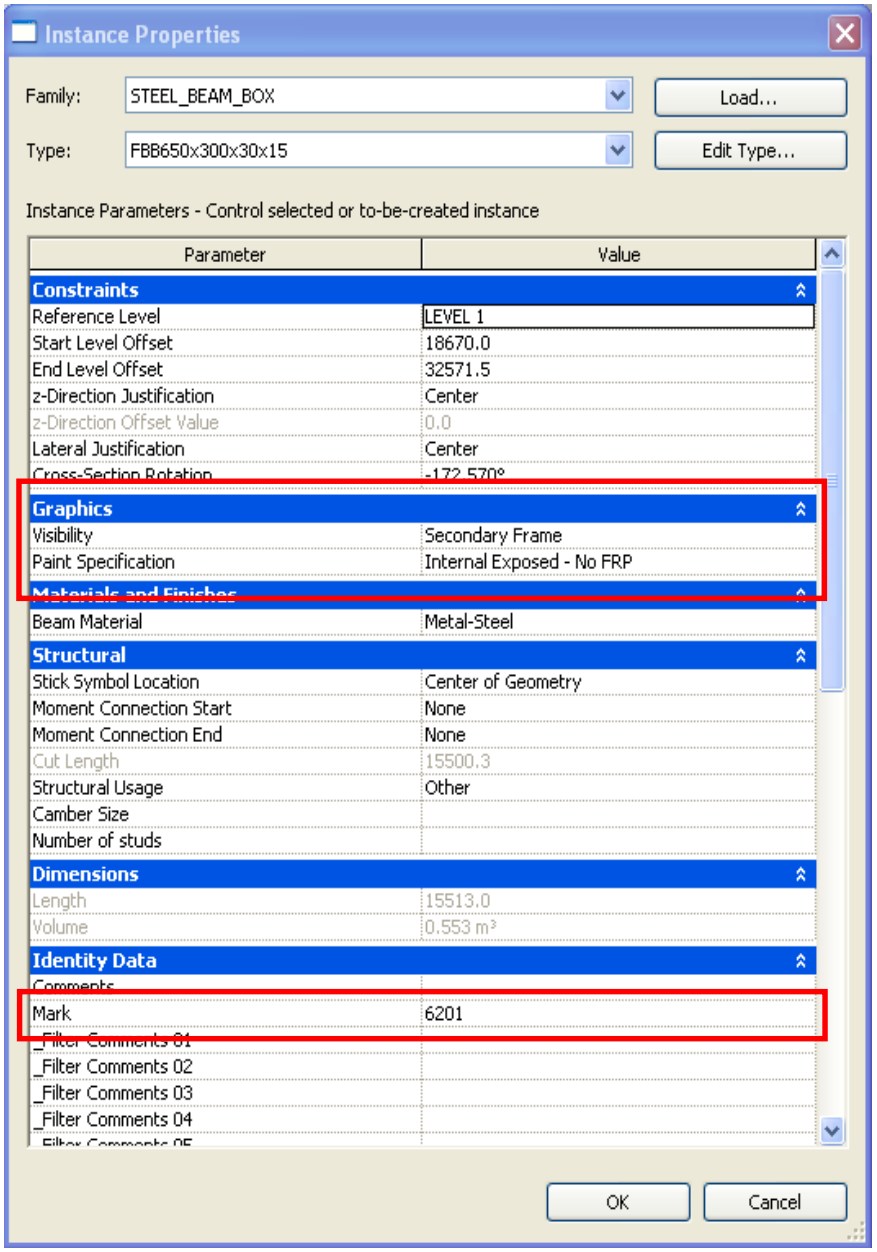
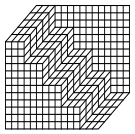

Instance Properties
Family: STEEL_BEAM_BOX
Load...
Type: FBB650x300x30x15
Edit Type...
Instance Parameters - Control selected or to-be-created instance
Parameter
Value
Constraints
Reference Level
LEVEL 1
Start Level Offset
18670.0
End Level Offset
32571.5
z-Direction Justification
Center
z-Direction Offset Value
0.0
Lateral Justification
Center
Graphics
Visibility
Secondary Frame
Paint Specification
Internal Exposed - No FRP
Beam Material
Metal-Steel
Structural
Stick Symbol Location
Center of Geometry
Moment Connection Start
None
Moment Connection End
None
Cut Length
15500.3
Structural Usage
Other
Camber Size
Number of studs
Dimensions
Length
15513.0
Volume
0.553 m³
Identity Data
Mark
6201
_Filter Comments 02
_Filter Comments 03
_Filter Comments 04
OK
Cancel



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DRIVING SPLINES

grasshopper

Excel: properties, loads, supports

ANALYSIS MODEL

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ROBOT RSA: PHASE 1

BH Scripted Link

REVIT SURFACES

ROBOT RSA: PHASE 2 / 3

ROBOT BARS

BH Scripted Link

BH Scripted Link

COMPLETE REVIT MODEL

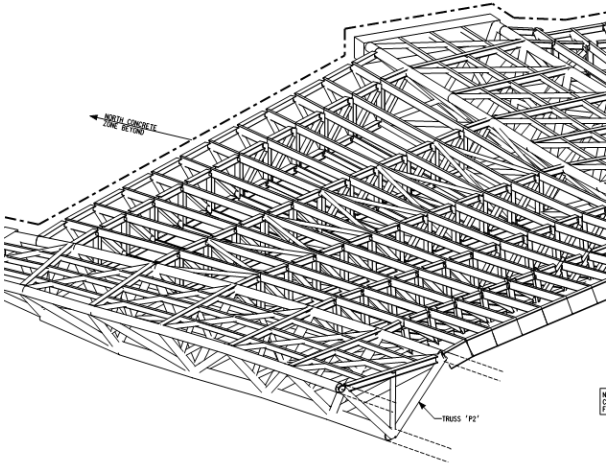
BH Scripted Link

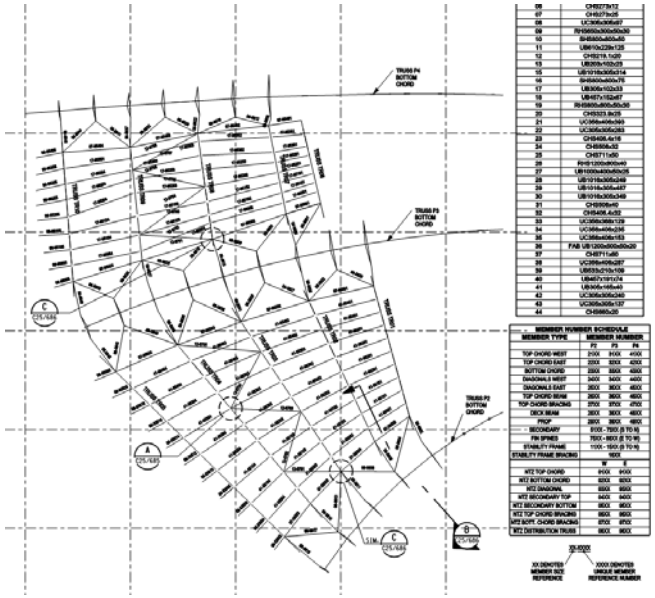
POST PROCESSING SCRIPTS: MEMBER DESIGN

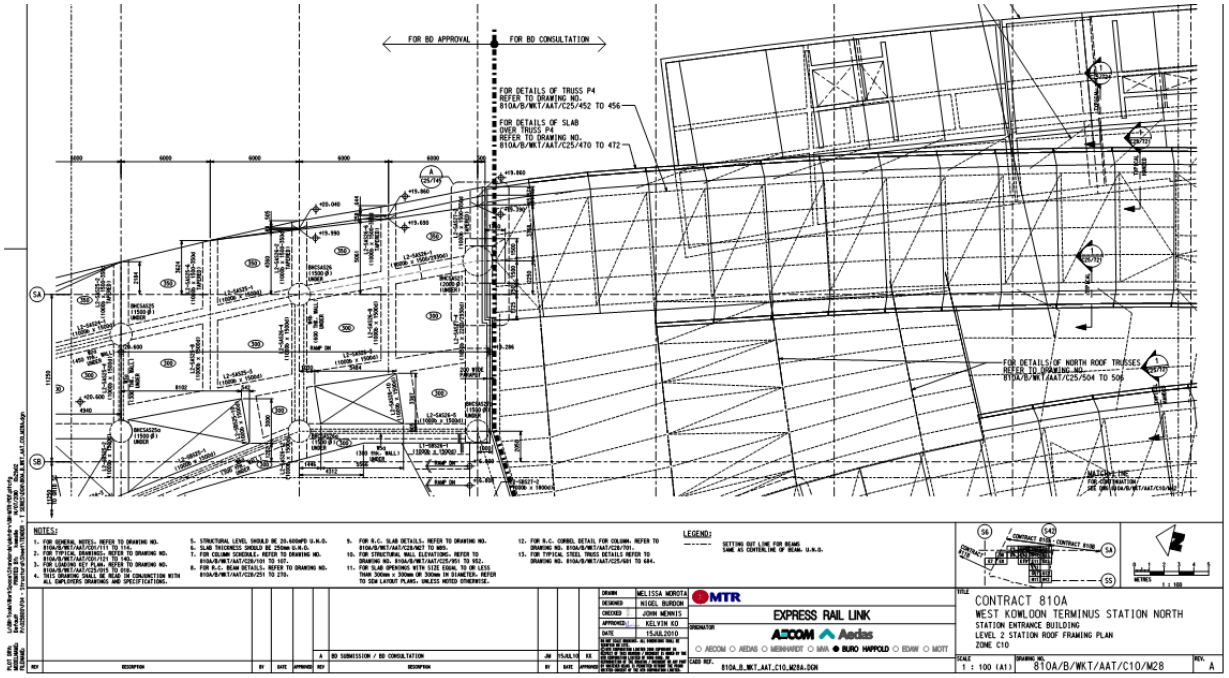
TAGGING

BH conversion script

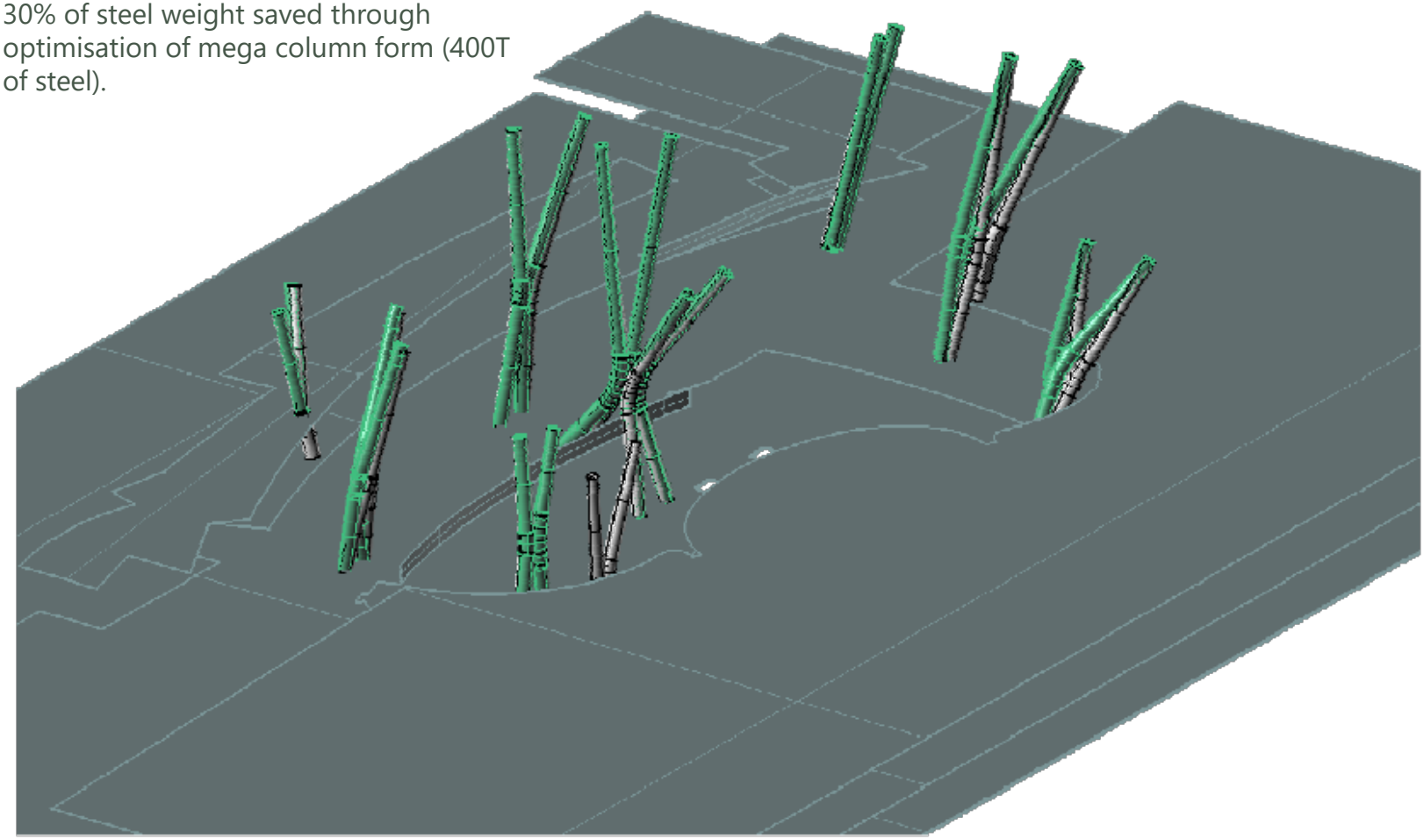
MICROSTATION







- 30% of steel weight saved through optimisation of mega column form (400T of steel).



Refined column form in gray

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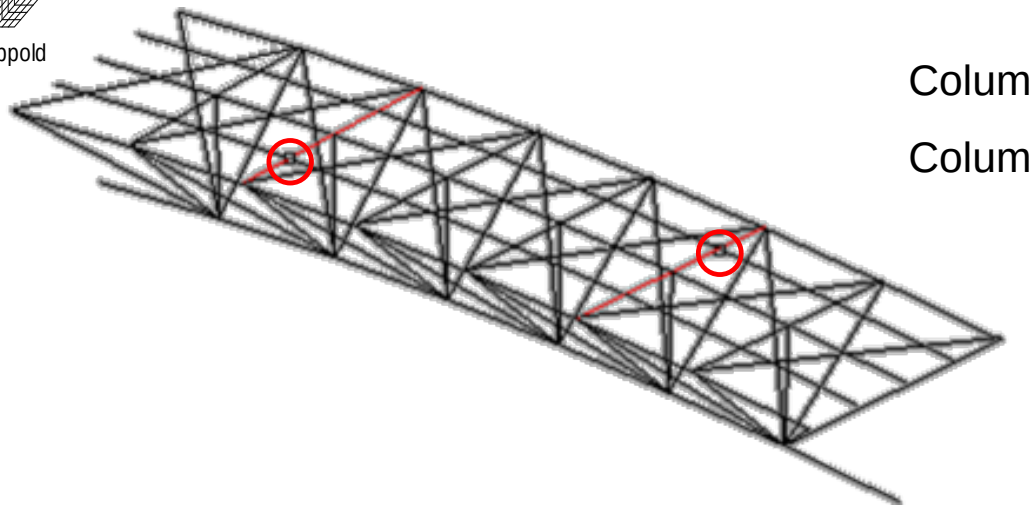
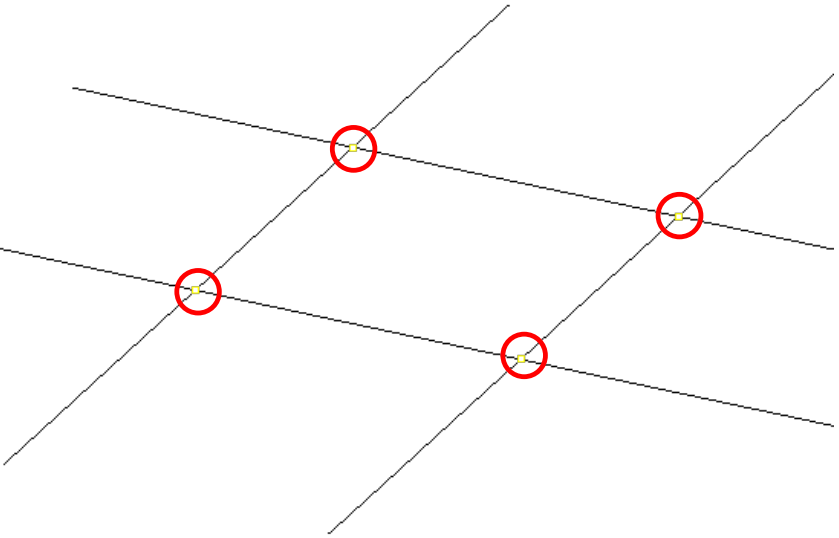
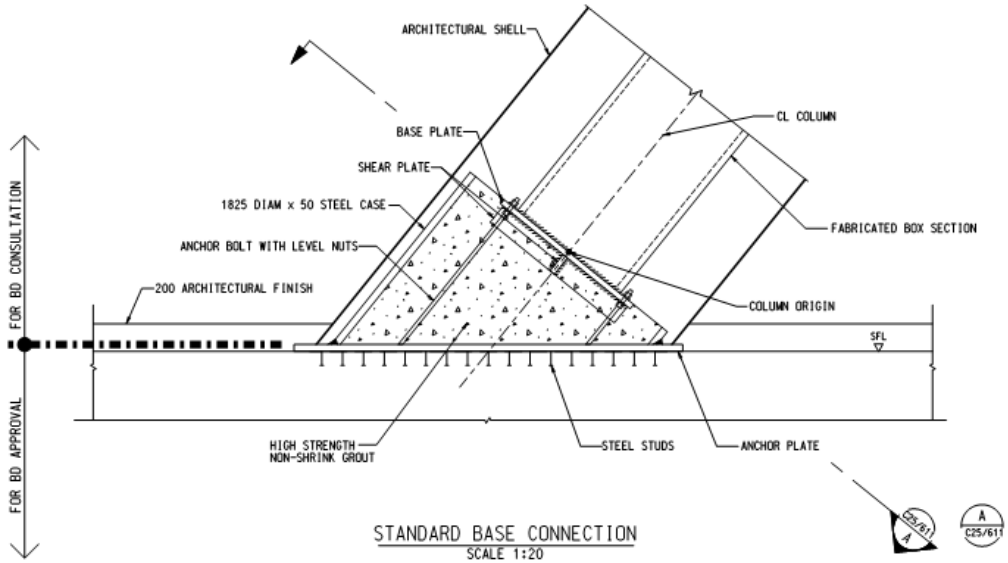
Constraints

Column base on grid-lines

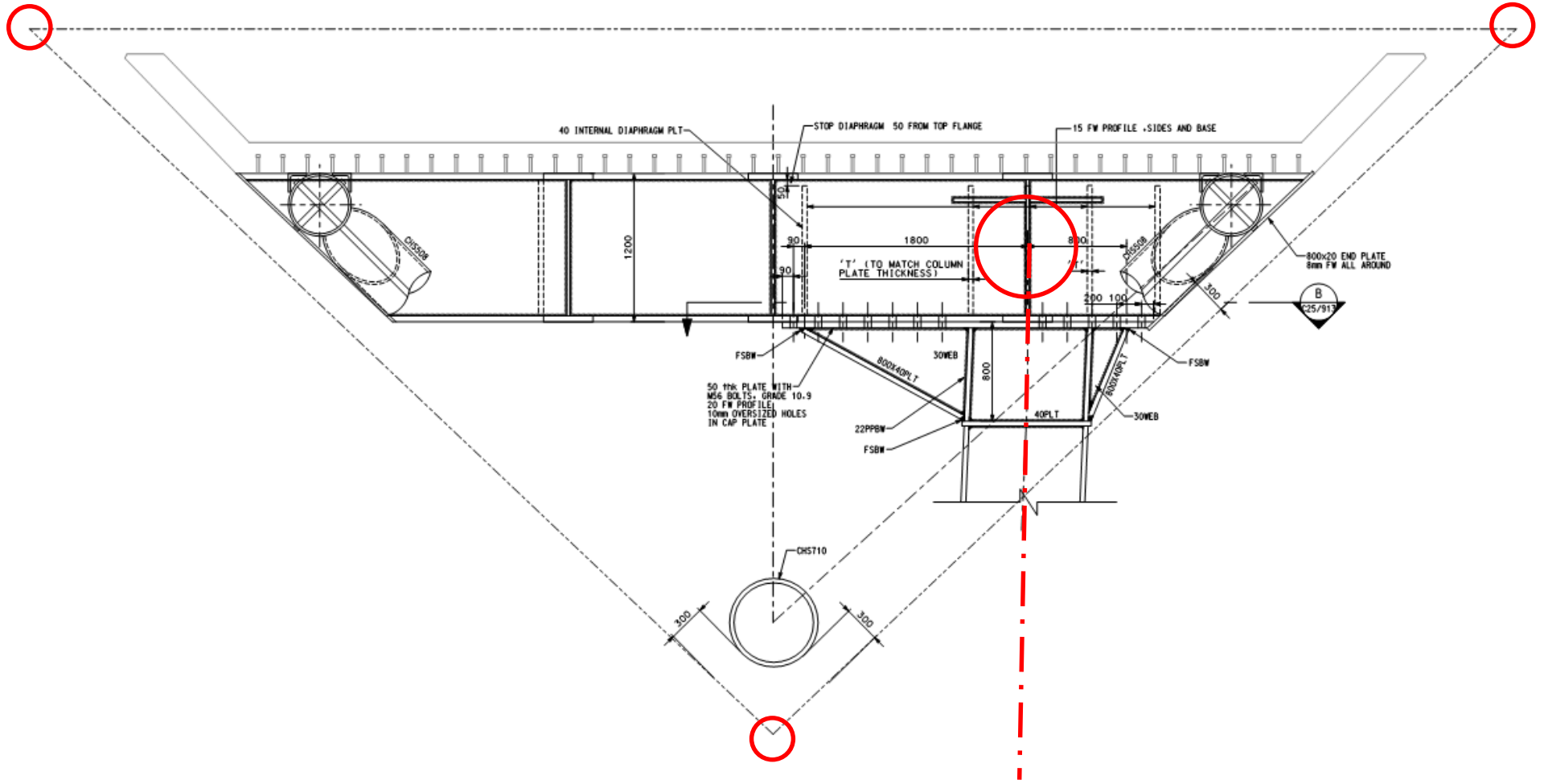
Column head to align with truss elements



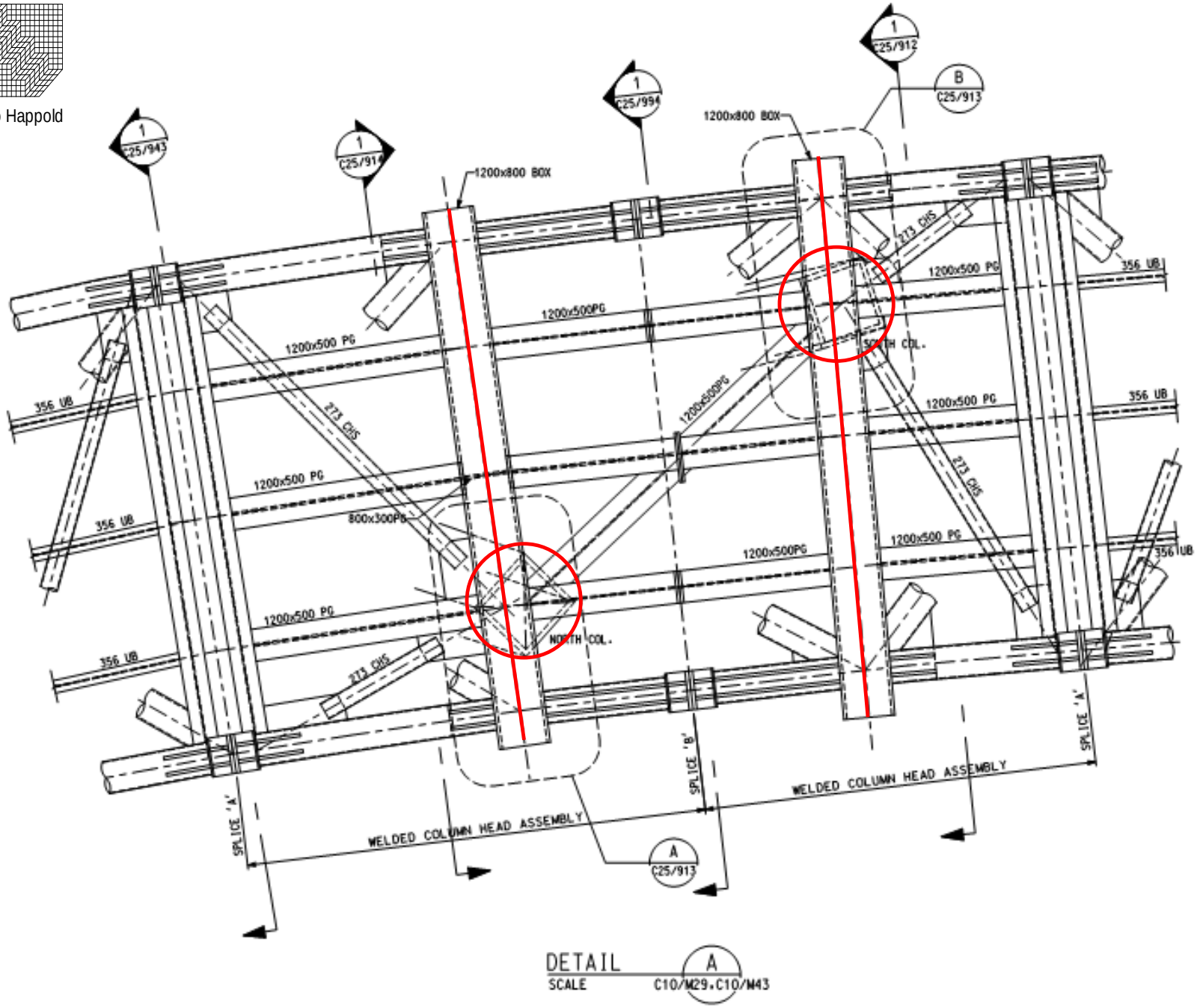




Buro Happold



Buro Happold



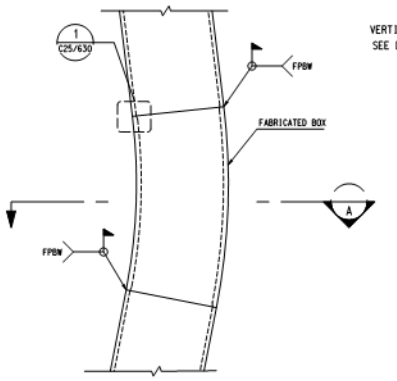
DETAIL A

SCALE C10/M29.C10/M43

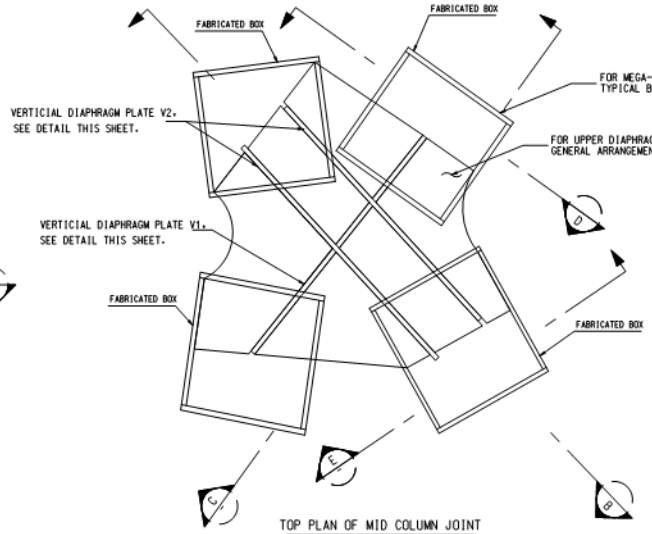
Buro Happold

Constraints

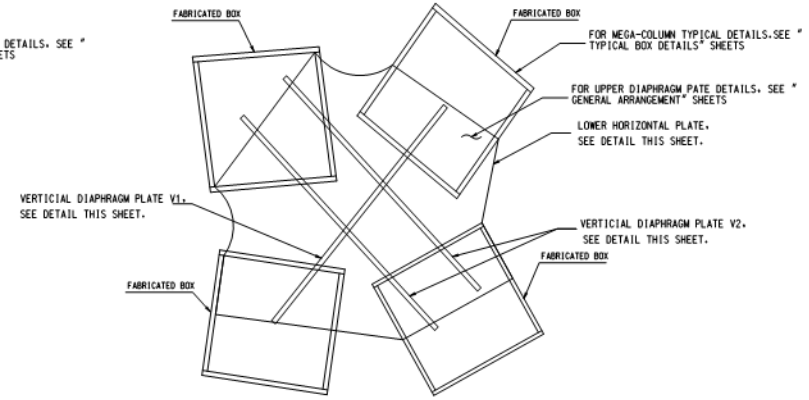
Node fabrication and construction



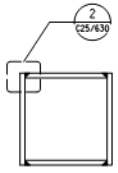
TYPICAL FABRICATED BOX JOINT
1:25



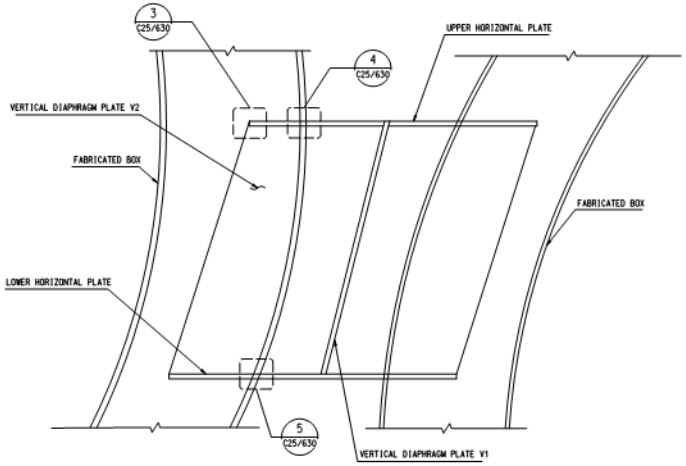
TOP PLAN OF MID COLUMN JOINT
1:25



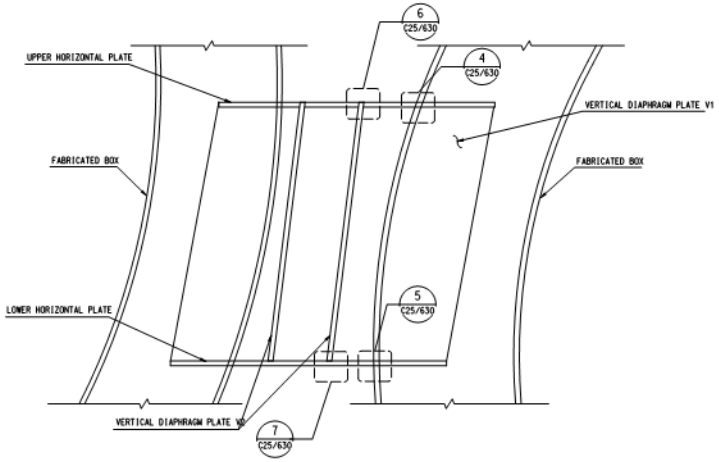
BOTTOM PLAN OF MID COLUMN JOINT
1:25



SECTION A
1:25

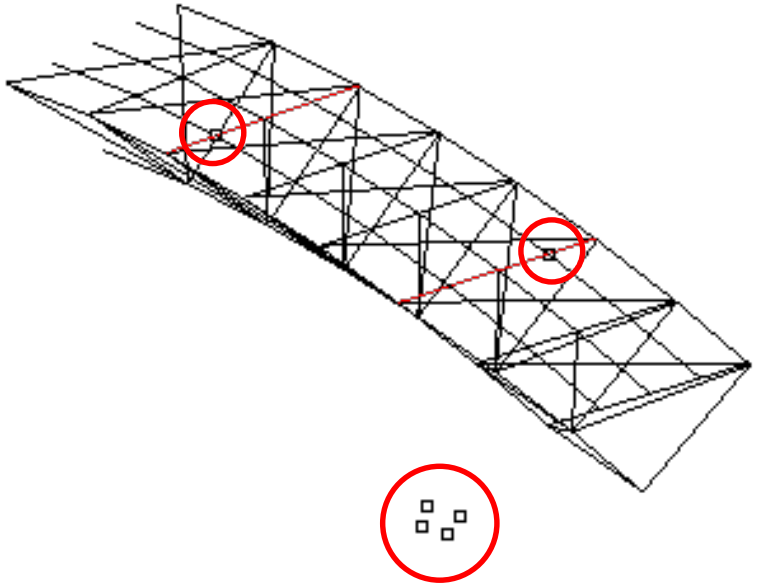


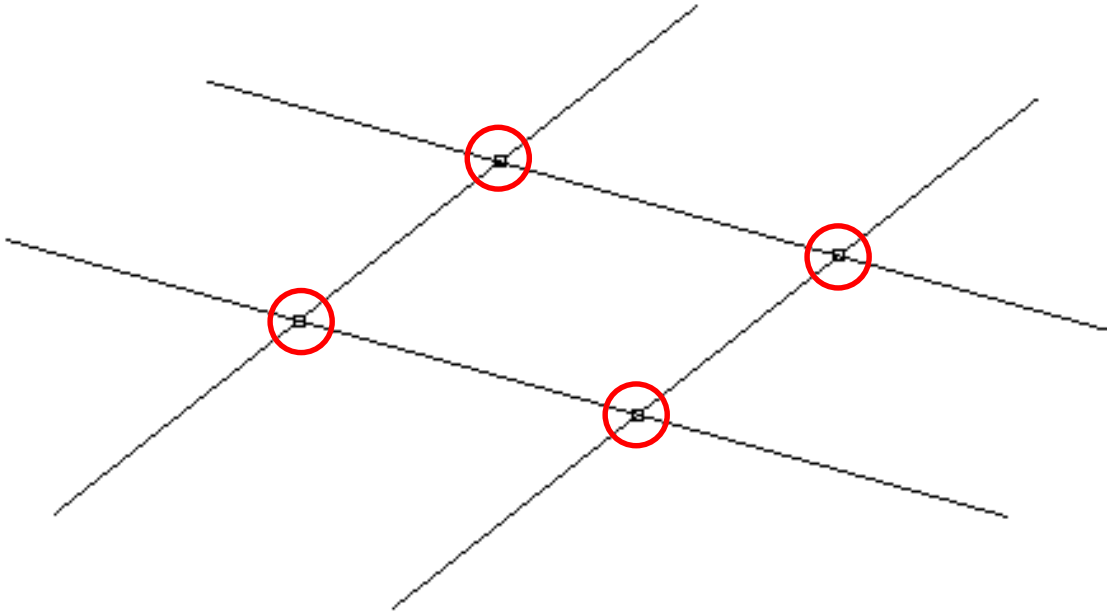
SECTION B
1:25



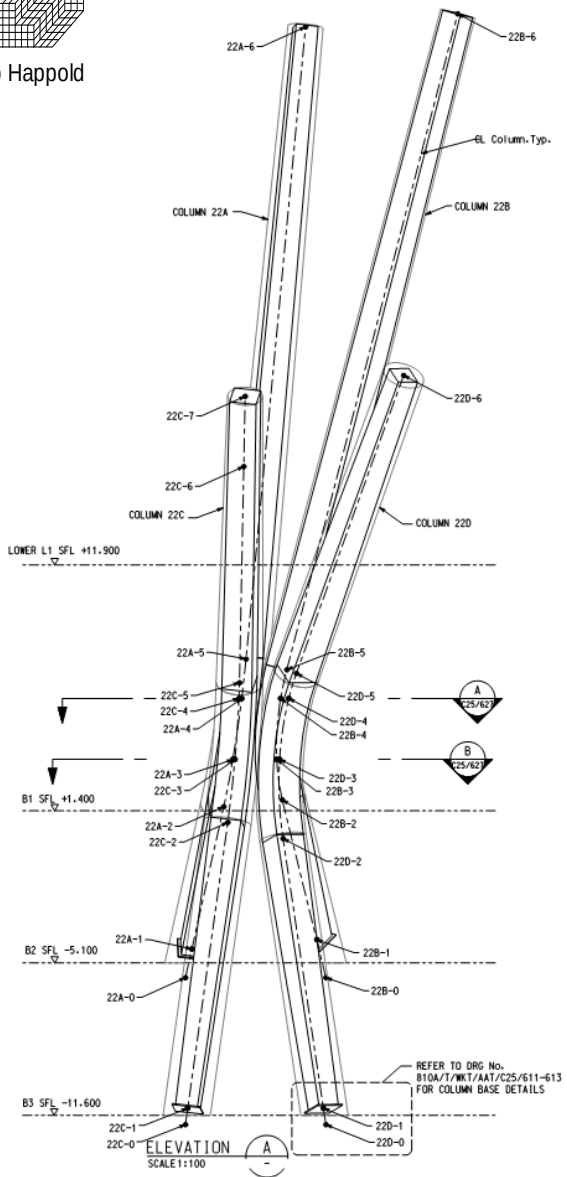
SECTION C
1:25

Buro Happold

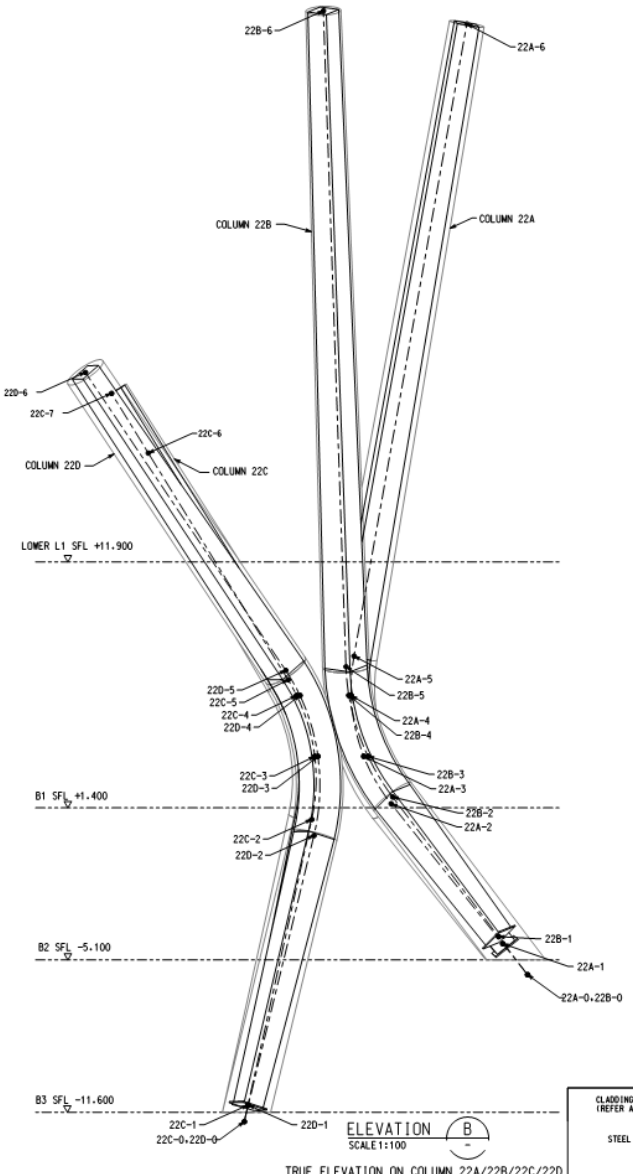




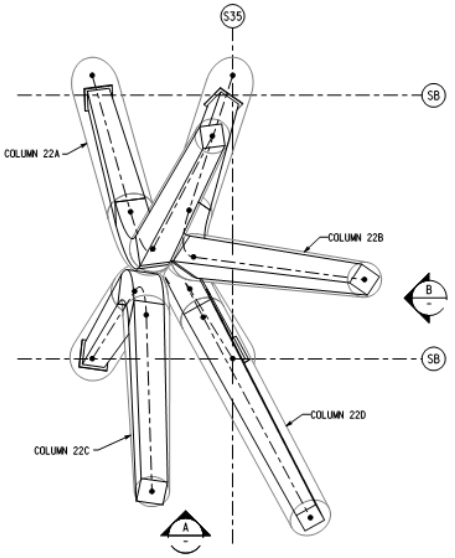
Buro Happold



TRUE ELEVATION ON COLUMN 22A/22B/22C/22D



TRUE ELEVATION ON COLUMN 22A/22B/22C/22D

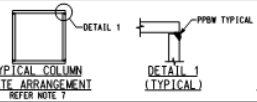


TRUE PLAN
1:100

METRES
1 : 100

NOTES:

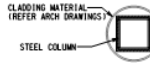
1. FOR GENERAL NOTES, REFER TO DRAWING NO. B10A/T/WKT/AAT/C01/111 TO 114.
2. FOR TYPICAL DRAWINGS, REFER TO DRAWING NO. B10A/T/WKT/AAT/C01/121 TO 140.
3. FOR LOADING KEY PLAN, REFER TO DRAWING NO. B10A/T/WKT/AAT/C25/015 TO 019.
4. THIS DRAWING SHALL BE READ IN CONJUNCTION WITH ALL EMPLOYERS DRAWINGS AND SPECIFICATIONS.
5. NODE COORDINATES ARE PROVIDED ALONG CL OF COLUMNS.
6. COLUMN BOX WIDTHS VARY LINEARLY BETWEEN NODES.
7. COLUMN BOX PLATES CONNECTED BY PARTIAL PENETRATION BUTT WELDS TYPICAL AND BY FULL STRENGTH BUTT WELDS IN JOINT ZONE EXTENDING 500 PAST TOP & BOTTOM DIAPHRAGM (REFER DETAIL).
8. FOR FIRE PROTECTION DETAILS REFER DRAWINGS.



TYPICAL COLUMN PLATE ARRANGEMENT
REFER NOTE 7

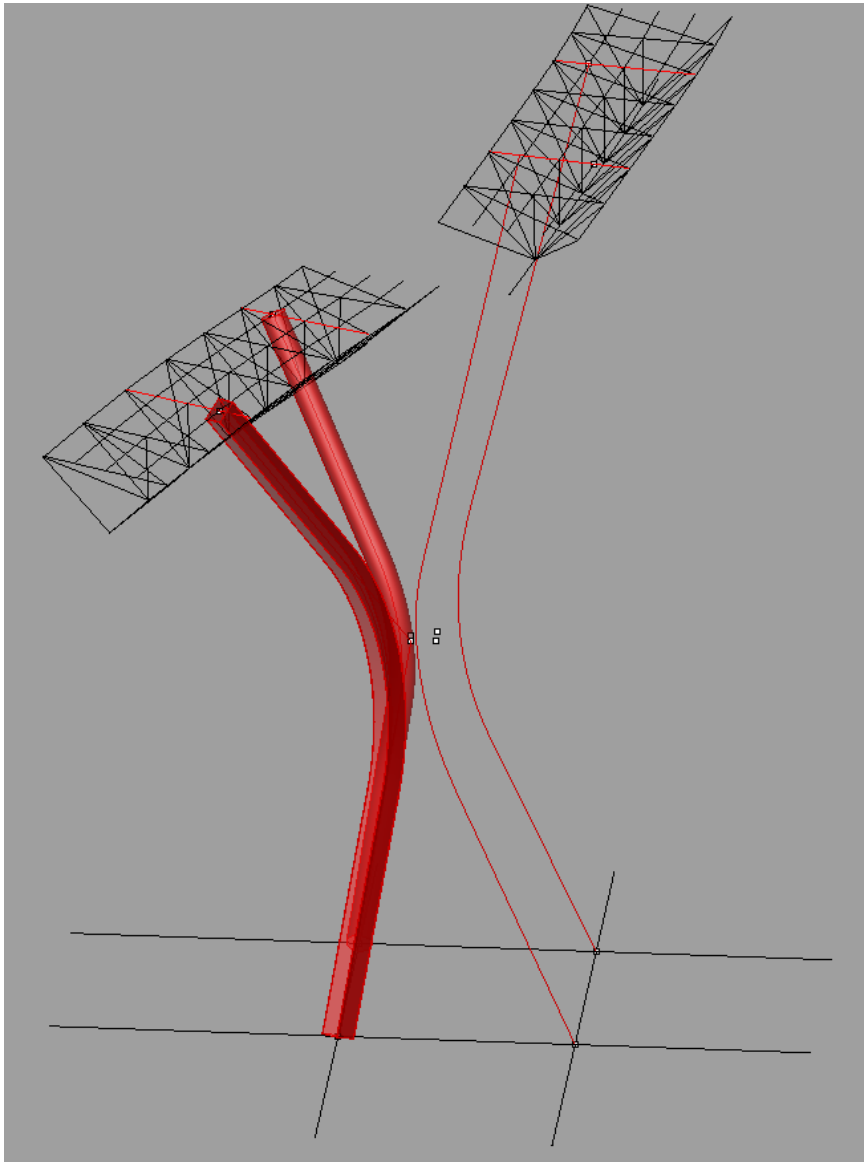
DETAIL 1 (TYPICAL)

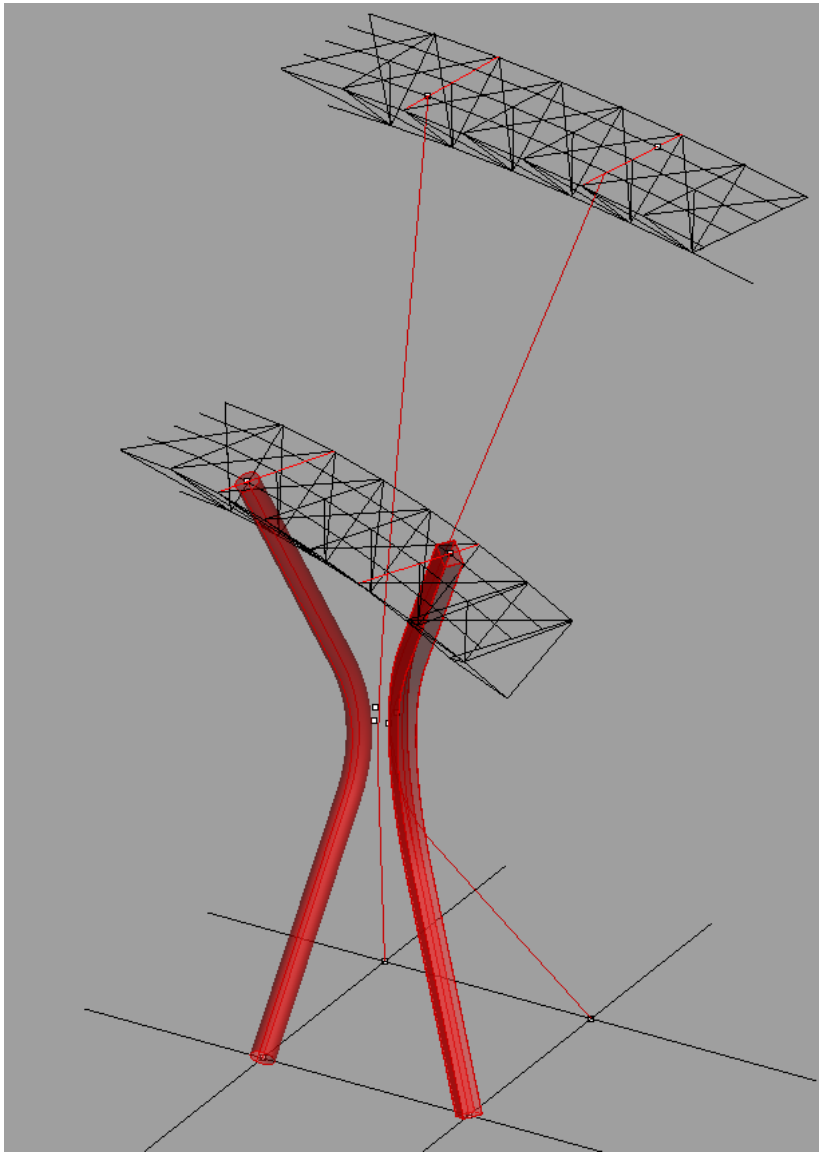
DETAIL 1 (NEAR JOINT ZONES)

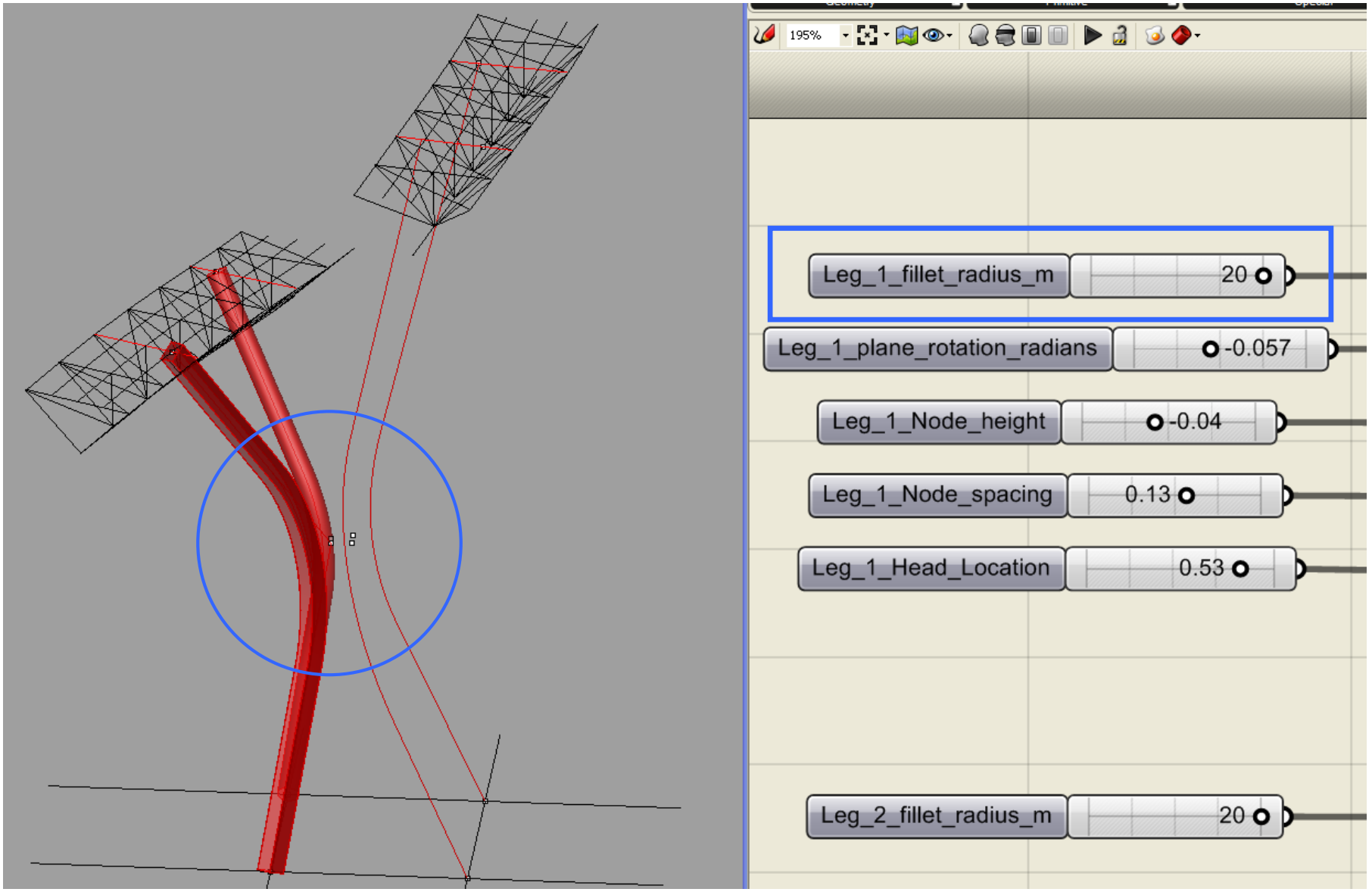


4-HOUR COLUMN FIRE RATING DETAILS

2-HOUR COLUMN FIRE RATING DETAILS






195%
Leg_1_fillet_radius_m
20
Leg_1_plane_rotation_radians
-0.057
Leg_1_Node_height
-0.04
Leg_1_Node_spacing
0.13
Leg_1_Head_Location
0.53
Leg_2_fillet_radius_m
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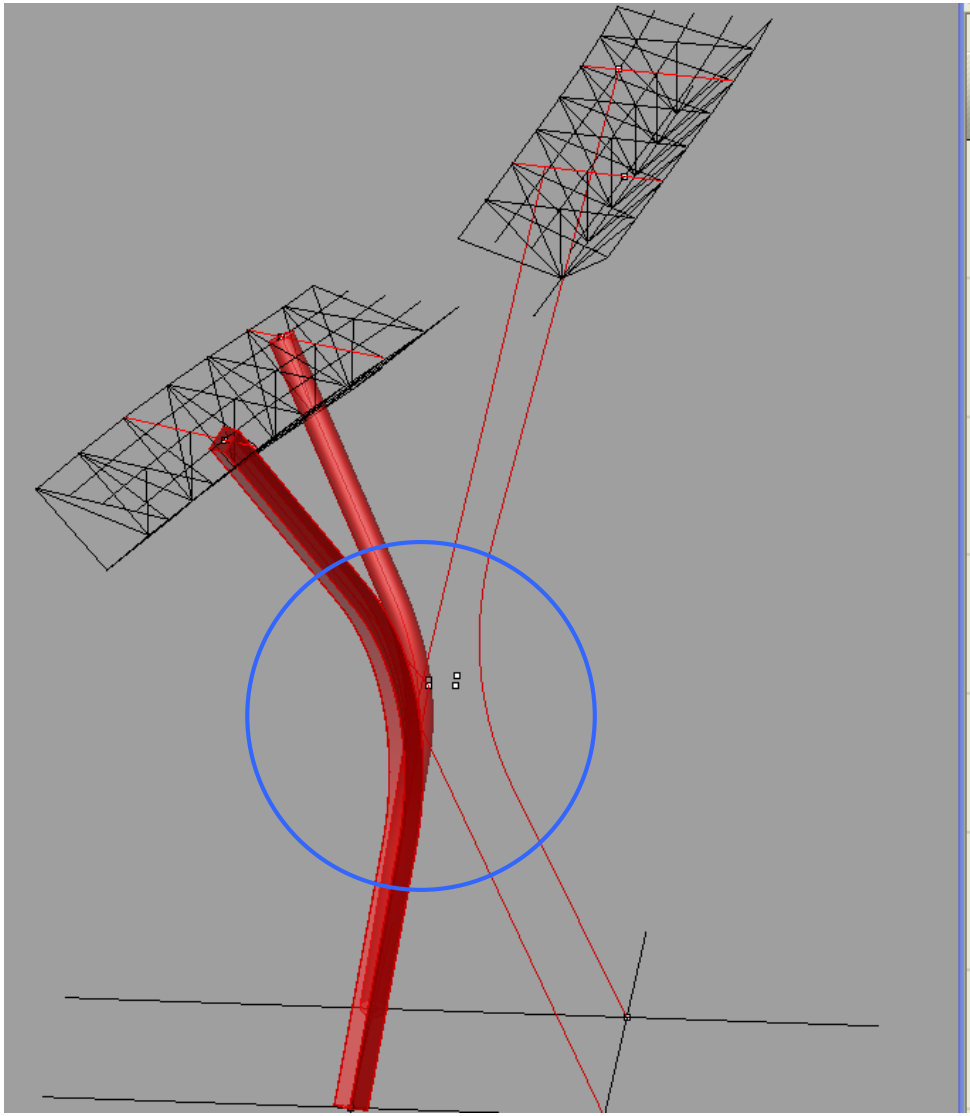

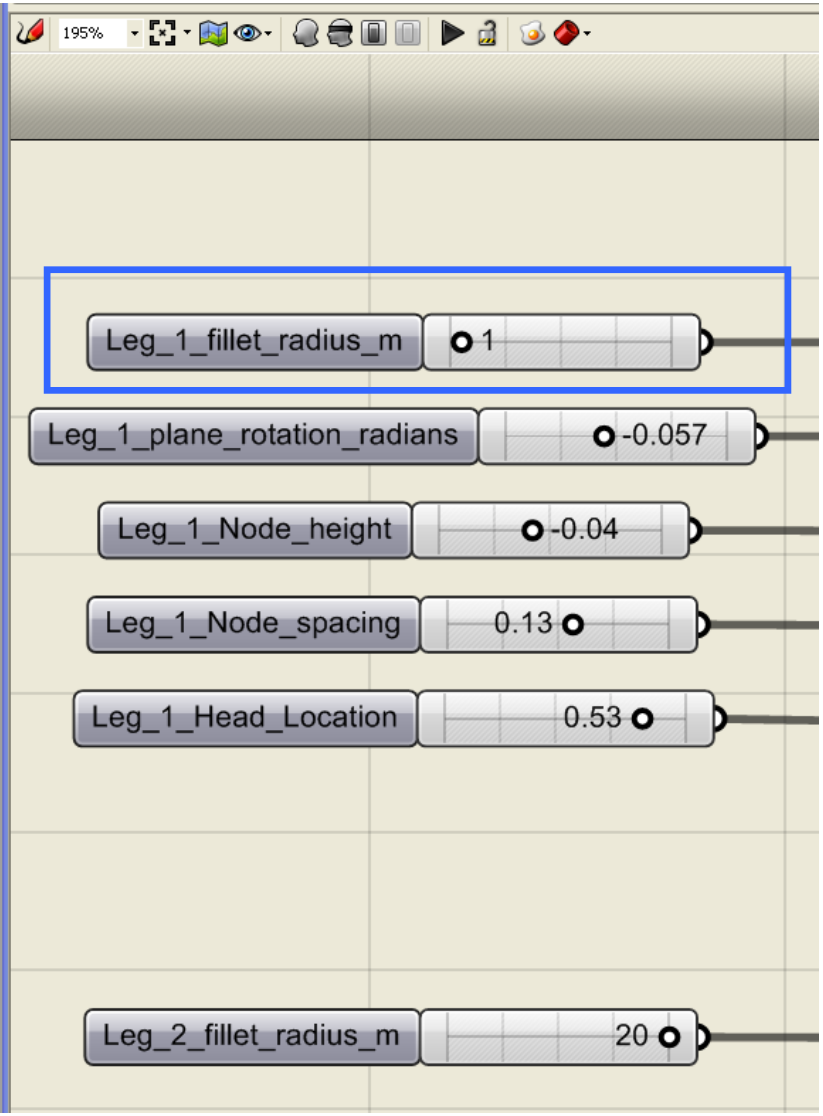
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Leg_1_plane_rotation_radians
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Leg_1_Node_height
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Leg_1_Node_spacing
0.13
Leg_1_Head_Location
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Leg_2_fillet_radius_m
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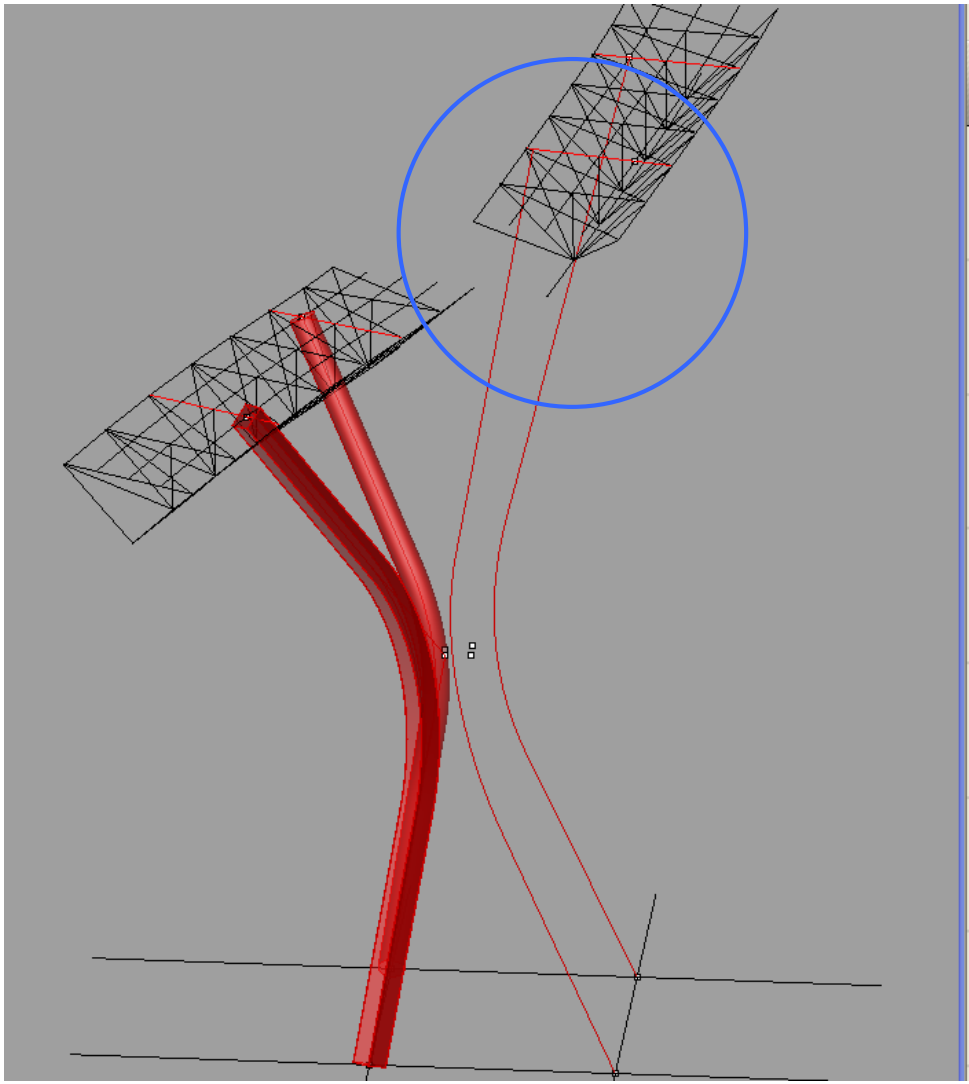
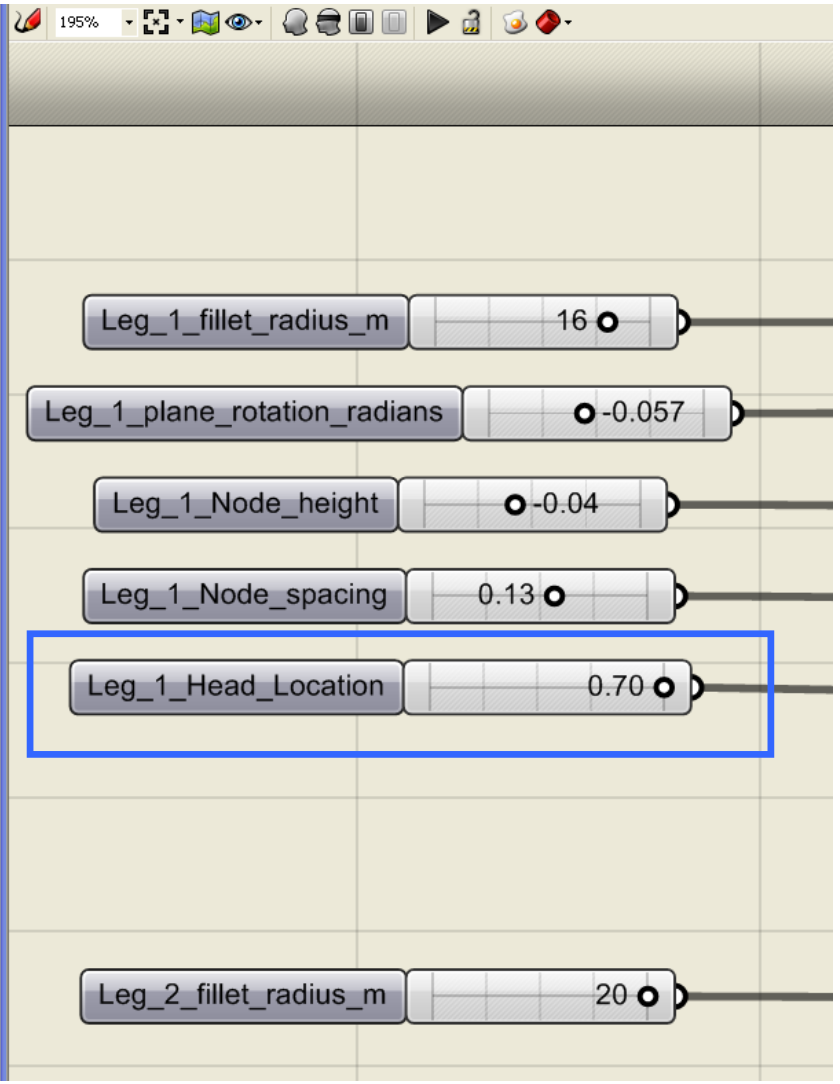
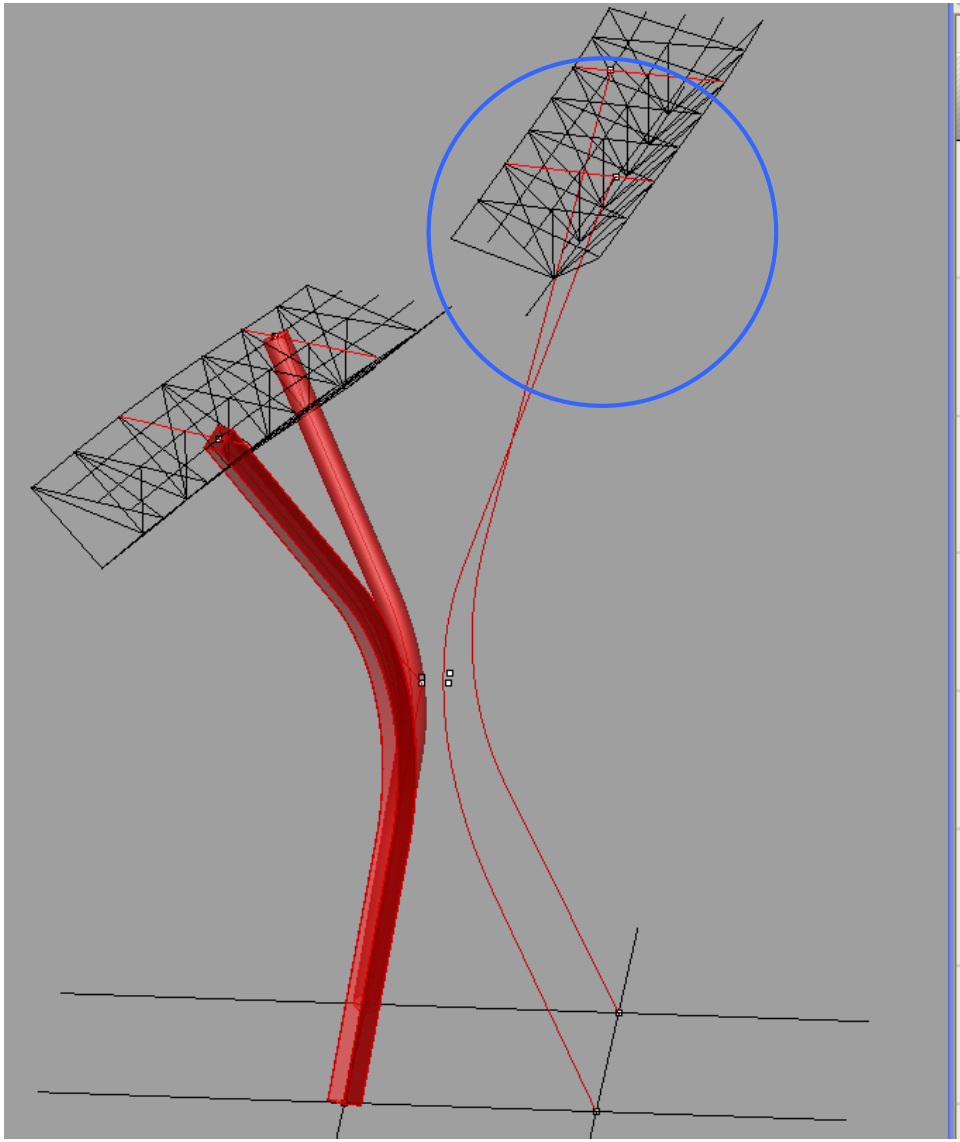
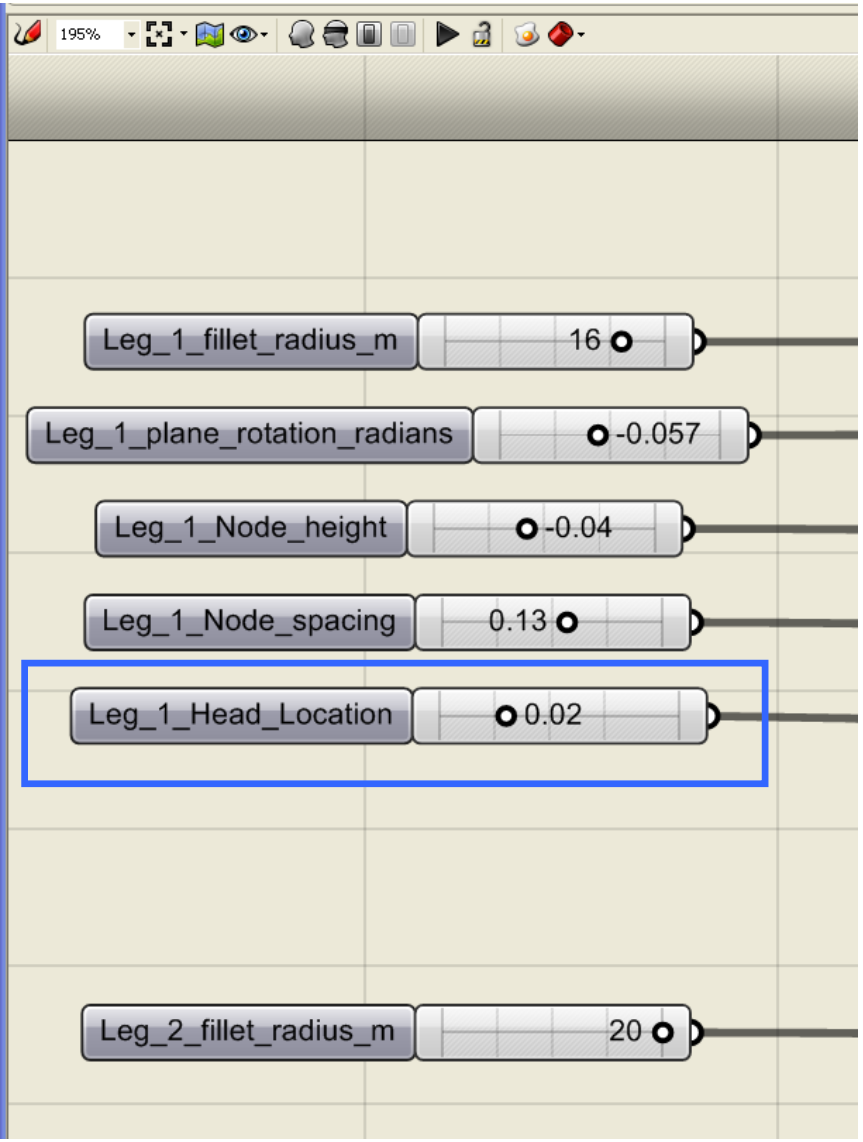



195%
Leg_1_fillet_radius_m
16
Leg_1_plane_rotation_radians
-0.057
Leg_1_Node_height
-0.04
Leg_1_Node_spacing
0.13
Leg_1_Head_Location
0.70
Leg_2_fillet_radius_m
20

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Leg_1_Node_height
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Leg_1_Node_spacing
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Leg_1_Head_Location
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Leg_2_fillet_radius_m
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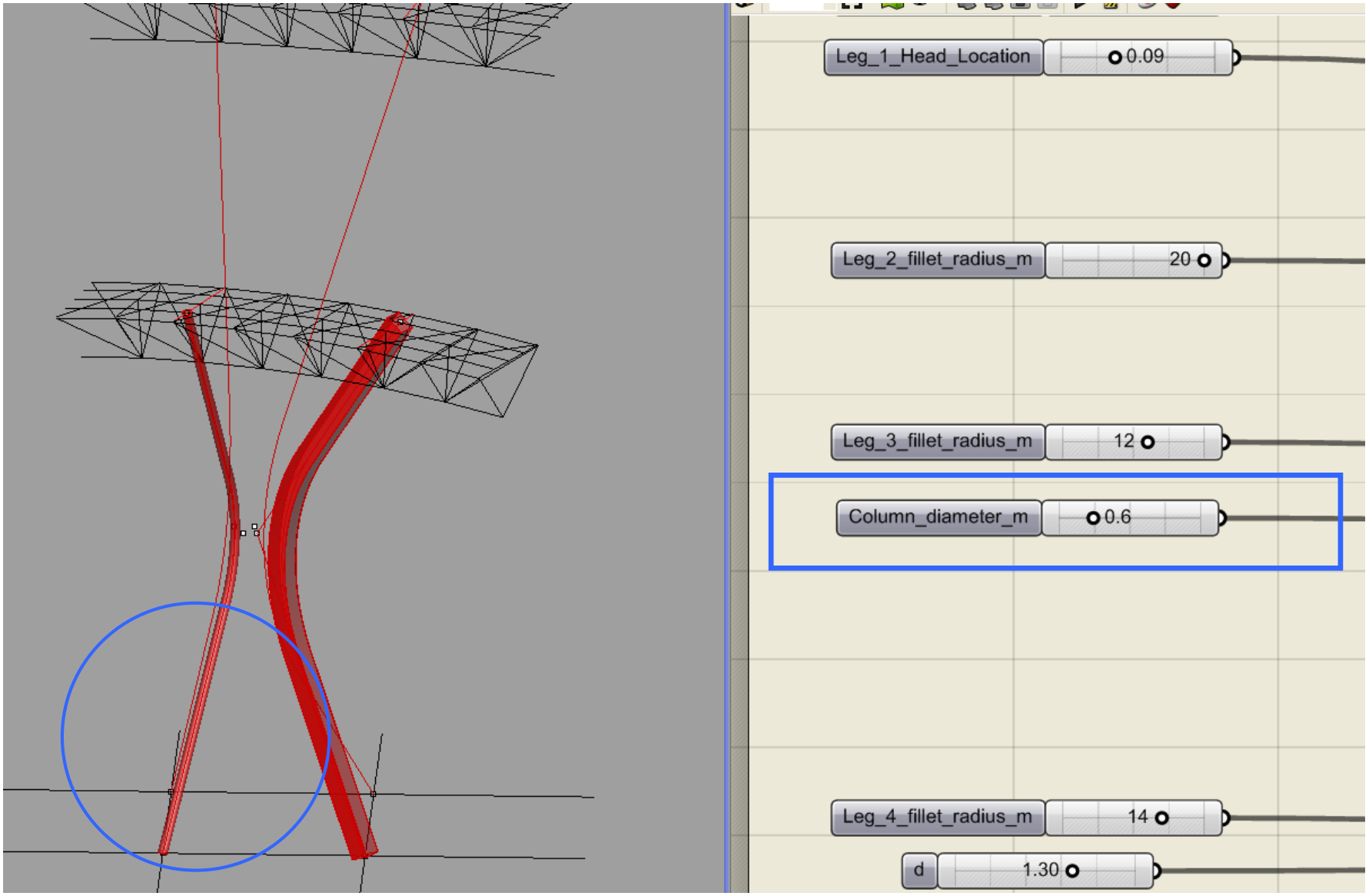
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Leg_4_fillet_radius_m
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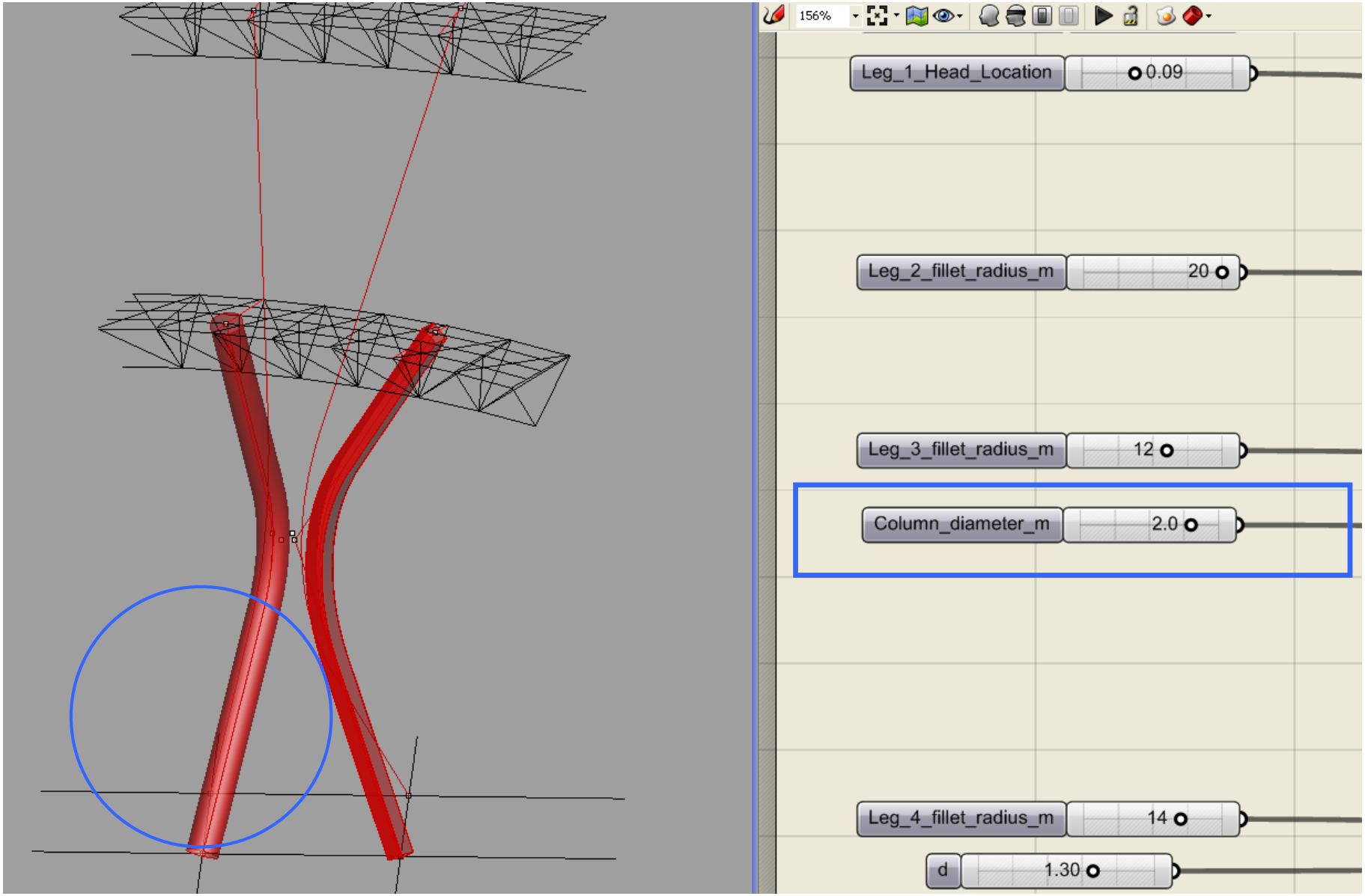
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Leg_1_Head_Location
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Leg_2_fillet_radius_m
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Leg_3_fillet_radius_m
12
Column_diameter_m
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Leg_4_fillet_radius_m
14
d
1.30

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