Optimizing Steelwork Design and Detailing Workflows from Concept to Fabrication

Matt Pearce

Principal Engineer,

Mott MacDonald

Martin Rolny

Head of Product Team,

IDEA Statica

CONNECT & CONSTRUCT SUMMIT

AUTODESK.
UNIVERSITY

Class objectives

1. Get familiar with various connection design workflows across the Autodesk AEC Collection

2. Find out about challenges in connection design from various real-life projects

3. Learn how to quickly deal with code-checking all types of connections to increase productivity

4. Get insight into CBFEM-based connection design and how it compares to traditional approaches

About the speaker

Matt Pearce

Principal Engineer at Mott MacDonald

Started with Mott MacDonald in 2007

Worked in UK, Hong Kong, Macau, China and Singapore

Key Projects: Waterloo, Twickenham Stadium Jakarta Velodrome, Wynn Palace, Macau

London 2012 Olympics Shooting Venue

Digital design leader for Building Structures

About the speaker

Martin Rolny

Head of Product Team at IDEA StatiCa with over 10 years of experience across development, testing and supporting CAE applications for structural engineers.

Overview

THE OUTCOMES

Lessons Learnt

Conclusions

THE IMPLEMENTATION

Practical Applications:

Waterloo Station

Jakarta Velodrome

THE SOLUTIONS

Technology Solutions

Concept Design

Detailed Design

IDEA Statica

THE CHALLENGE
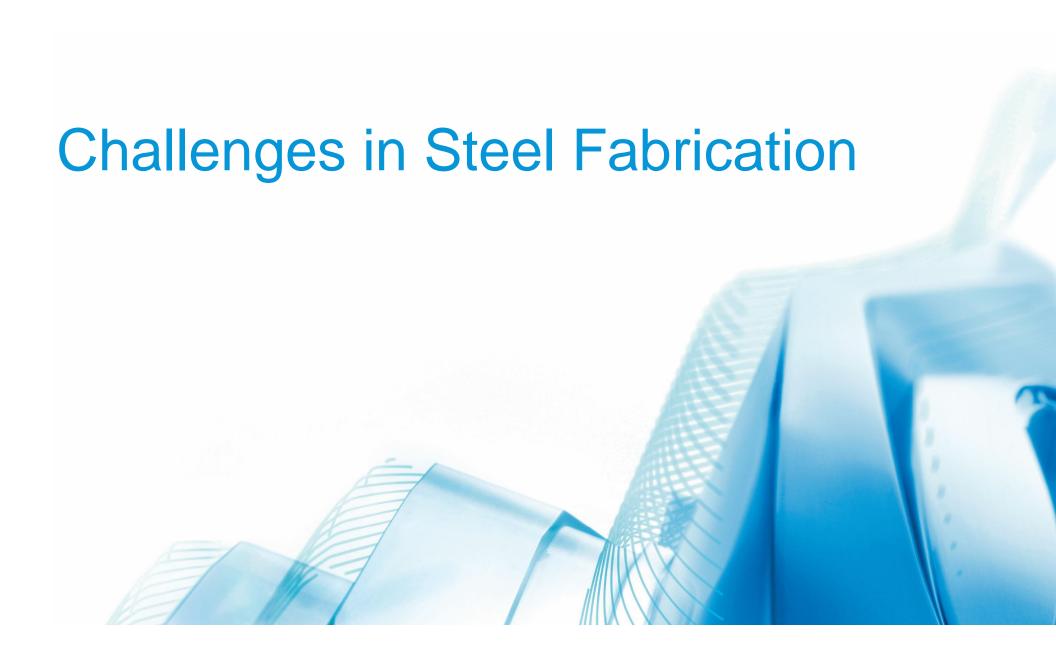
Priorities of fabricators

Priorities of engineers

Challenges in Steel Fabrication

What are the priorities for fabricators?

TIME

Meet design and construction schedule

Minimize time on site

Minimize fabrication time

Minimize changes and rework

What are the priorities for fabricators?

COST

Time is money!

Minimize materials

Minimize temporary works

What are the priorities for fabricators?

QUALITY

Quality control during fabrication

Construction defects minimized

SAFETY

Safe access

Stability during construction

What are the priorities for engineers?

SAFETY

Safe design under all load cases

Safe construction / dismantling

What are the priorities for engineers?

QUALITY

Fulfills functional and aesthetic requirements

Construction defects minimized

What are the priorities for engineers?

I'm not convinced we've wasted enough time on this.

someecards

TIME AND COST

Meet design and construction schedule

Control design changes

Time is still money

Minimize materials

Some Common Ground?

CONTRACTOR

ENGINEER

TIME

COST

QUALITY

SAFETY

Technology Solutions

Building Information Modelling

Structural Analysis and Design

Mott MacDonald

Fabrication Modelling

Bourne Steel

Visual Programming

CNC Machining and Robotics
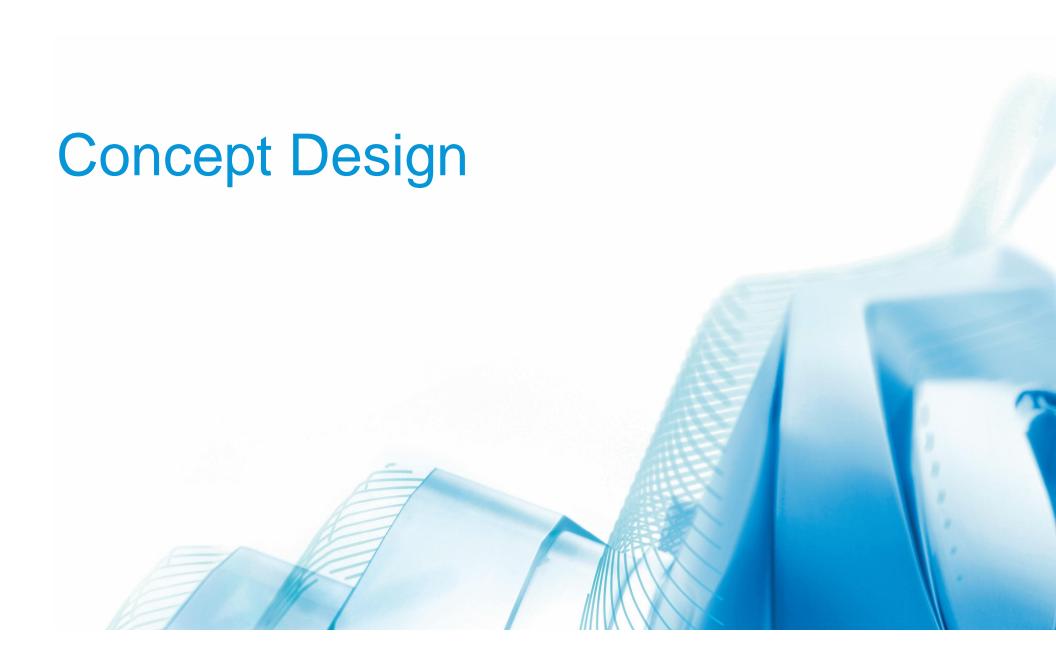
Photo credit goes here

Concept Design
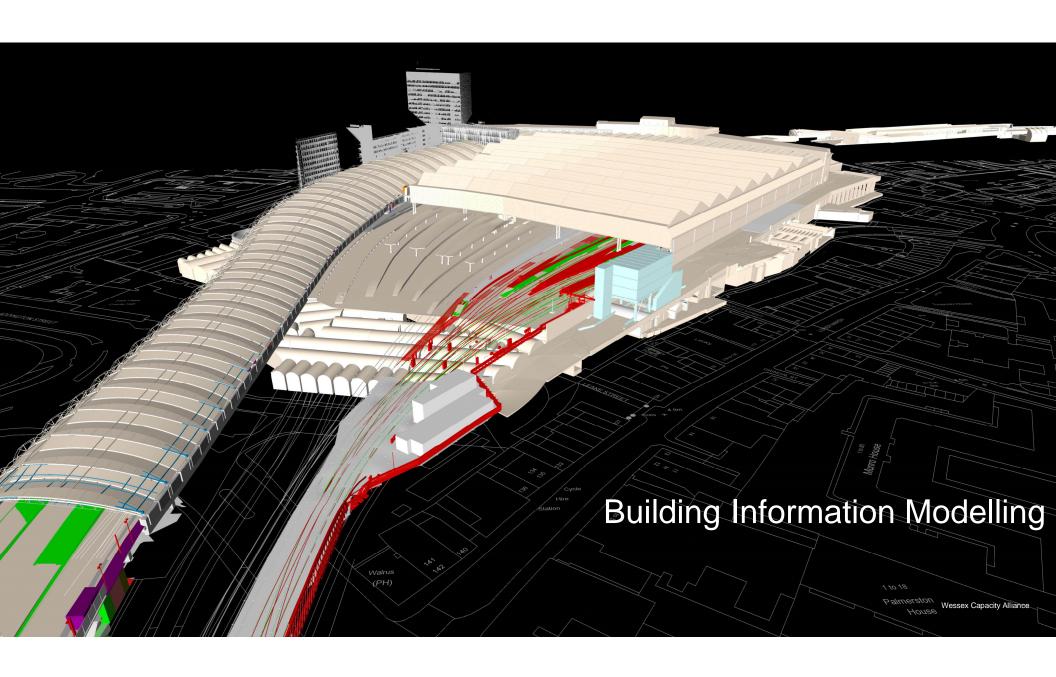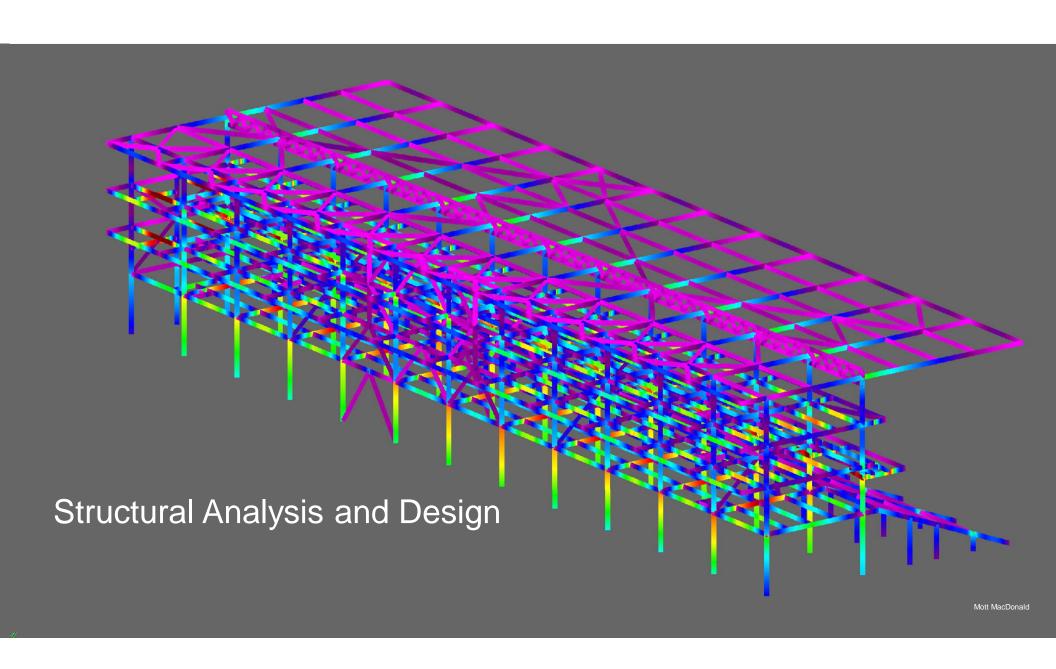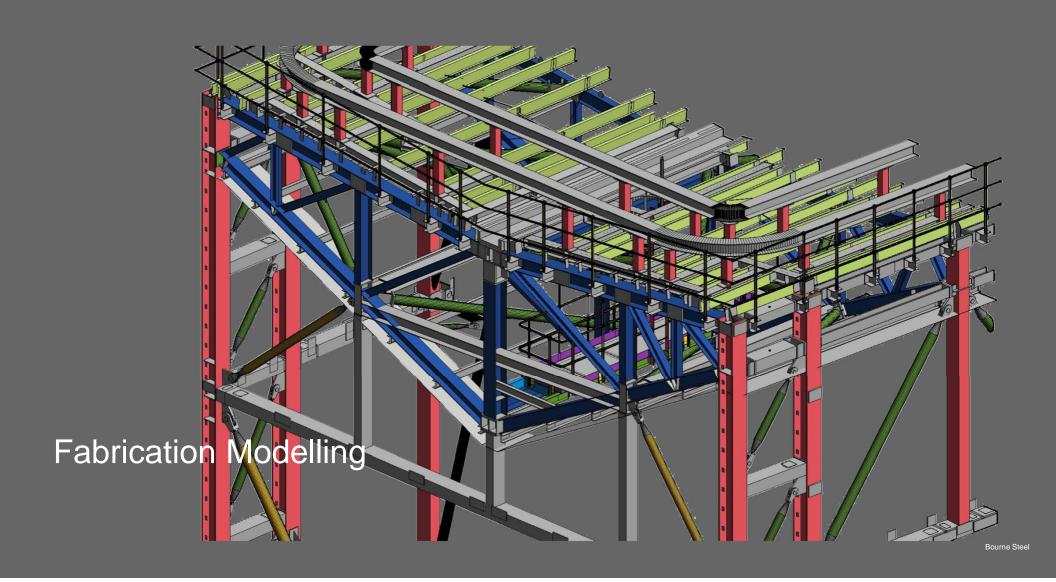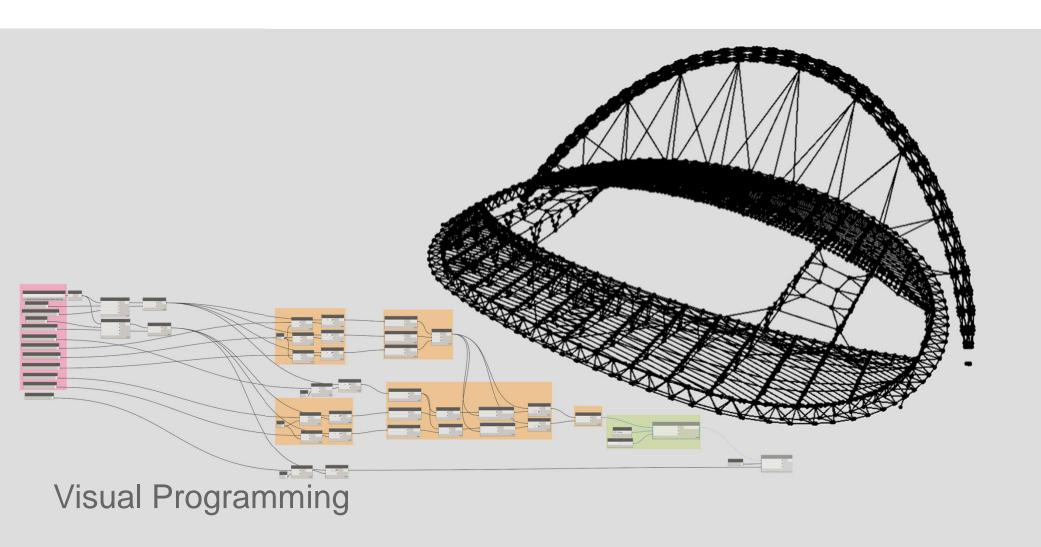
Concept Design Objectives

Define an outline design that meets the requirements of the design brief
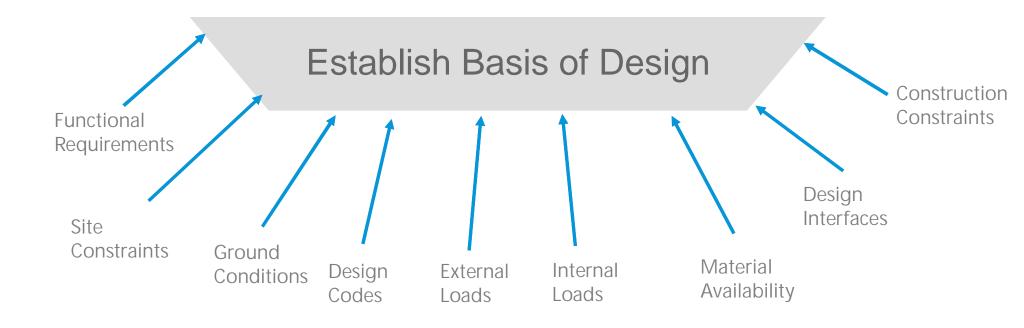
- Establish basis of Design
- Present conceptual design
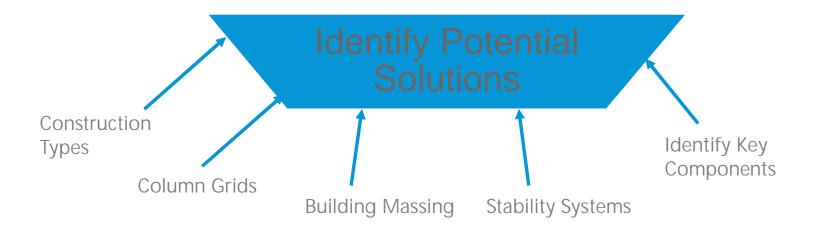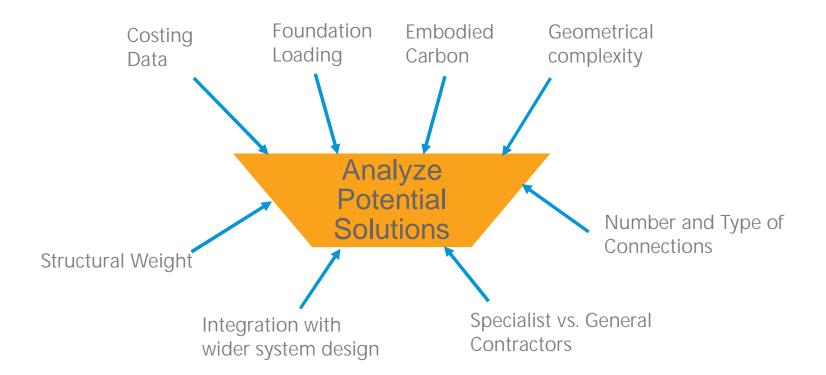- Create design brief for subsequent design stages

Concept Design - Process

Establish Basis of Design

Identify Potential Solutions
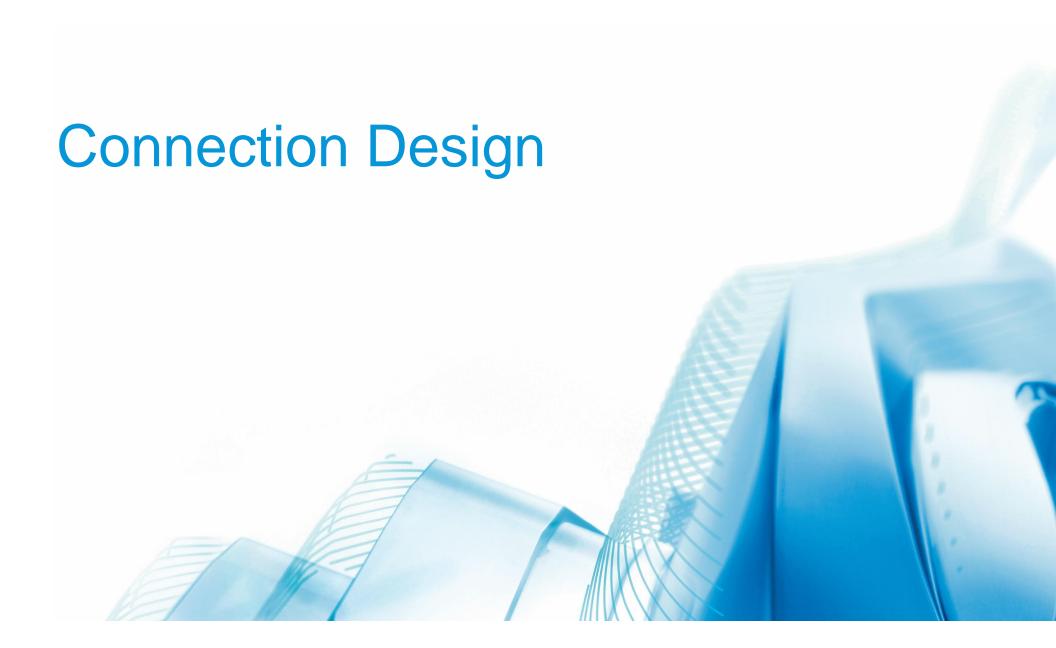
Analyze Potential Solutions

Preferred Solution

Concept Design - Process

Establish Basis of Design

Functional
Requirements

Construction
Constraints

Site
Constraints

Ground
Conditions

Design
Codes

External
Loads

Internal
Loads

Material
Availability

Design
Interfaces

Concept Design - Process

Identify Potential Solutions

Construction Types

Column Grids

Building Massing

Stability Systems

Identify Key Components

Concept Design - Process

Costing Data

Foundation Loading

Embodied Carbon

Geometrical complexity

Analyze Potential Solutions

Structural Weight

Number and Type of Connections

Integration with wider system design

Specialist vs. General Contractors

Detailed Design

Objectives

Produce detailed design information to enable fabricator to produce fabrication information:

- Confirming design assumptions made at concept design
- Detailed coordination with other design disciplines
- Finalize structural arrangement and sizes
- Design of connections

Connection Design

Benefits, approach, theory, model, verification, validation.

IDEA StatiCa FOR STRUCTURAL ENGINEERING

Development team with 30 years of experience of making innovative software for structural engineers in more than 70 countries.

IDEA StatiCa®

Calculate yesterday's estimates

Engineering software dedicated to structural design and code-check of joints, cross sections, beams and other details.

Thousands of licenses around the world

Software results validated by universities

Linked to major CAE/CAD programs
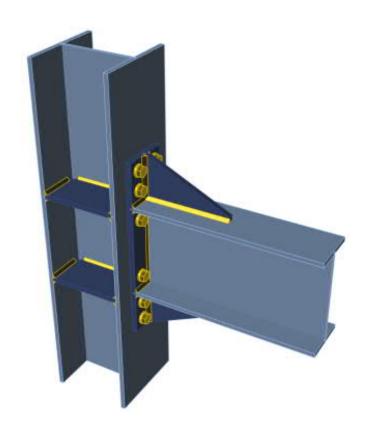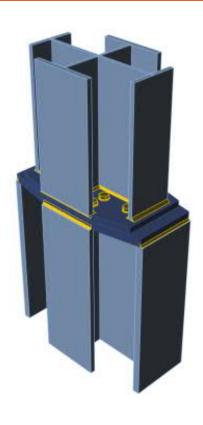
THE CHALLENGE

STANDARD	NON-STANDARD
Easy joint	Difficult joint

STANDARD	NON-STANDARD
Easy joint	Difficult joint

STANDARD — Design books

NON-STANDARD
- Advanced scientific model
- Excel spreadsheet
- Estimation
- Avoid using the joint

NUMBER OF JOINTS	TIME SPENT

NUMBER OF JOINTS

30 %
Difficult joint

70 %
Easy joint
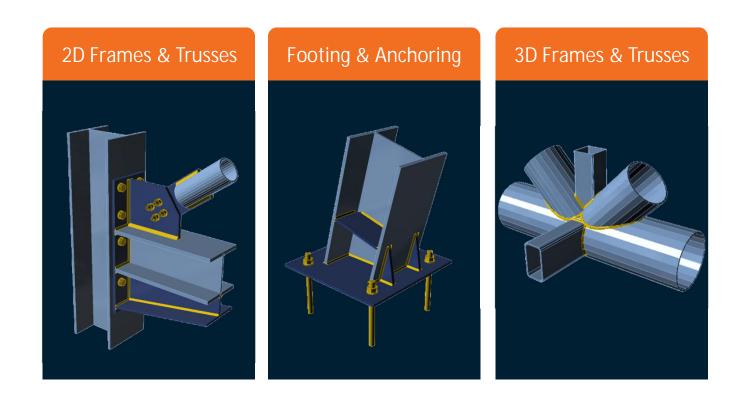
TIME SPENT

30 %
Easy joint

70 %
Difficult joint

SOLUTION

ALL TYPES OF JOINTS

2D Frames & Trusses

Footing & Anchoring
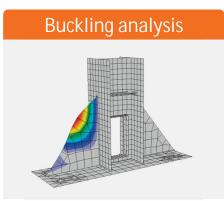
3D Frames & Trusses
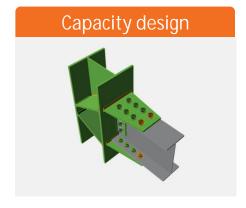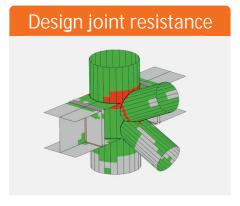
DESIGN WITH IDEA StatiCa CONNECTION

Stress/strain analysis

Buckling analysis

Stiffness analysis

Capacity design

Design joint resistance

Overall check

WORKFLOW

CAD BIM import
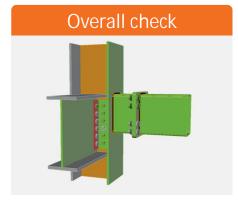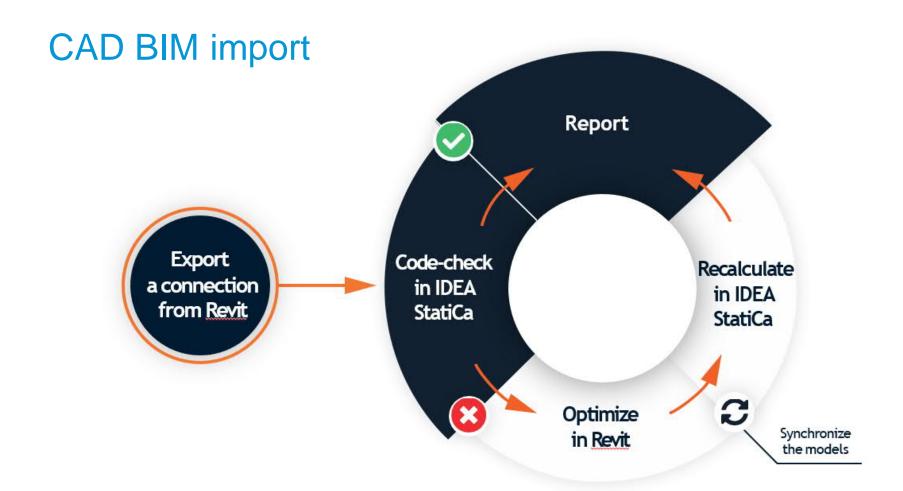
Live Demonstration

Case Study - Waterloo

Image caption goes here

2018: Waterloo Station Wessex Capacity Alliance

- Project
  - Waterloo Station Wessex Capacity Alliance (2015-2018)
- Client
  - Network Rail / Bourne Engineering Ltd.
- Location
  - London UK
- Key Features
  - Reinstatement of the old Eurostar terminal (5 Platforms)
  - Additional pedestrian access to platforms, LU and Waterloo station (Stairs, lifts and escalators)
  - New infill roof and bridge to connect WIT to Waterloo station

Concept Design - Key Challenges

6	100M	150Y	1
TRAIN LINES BENEATH STRUCTURE	PASSENGERS PER YEAR	AGE OF WATERLOO STATION	ACCESS ROAD TO SITE
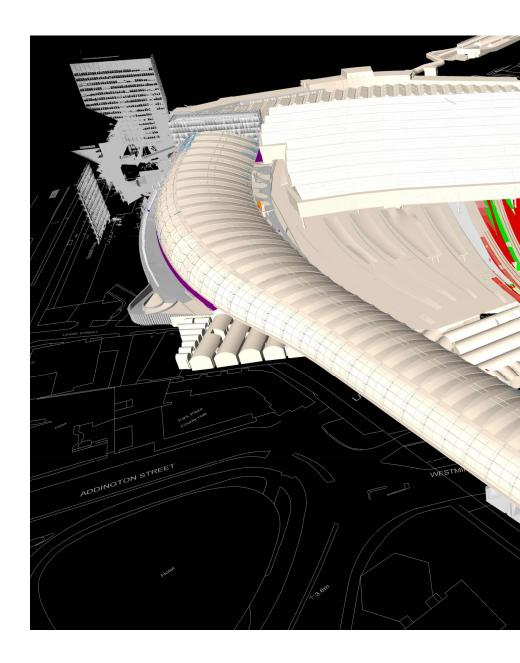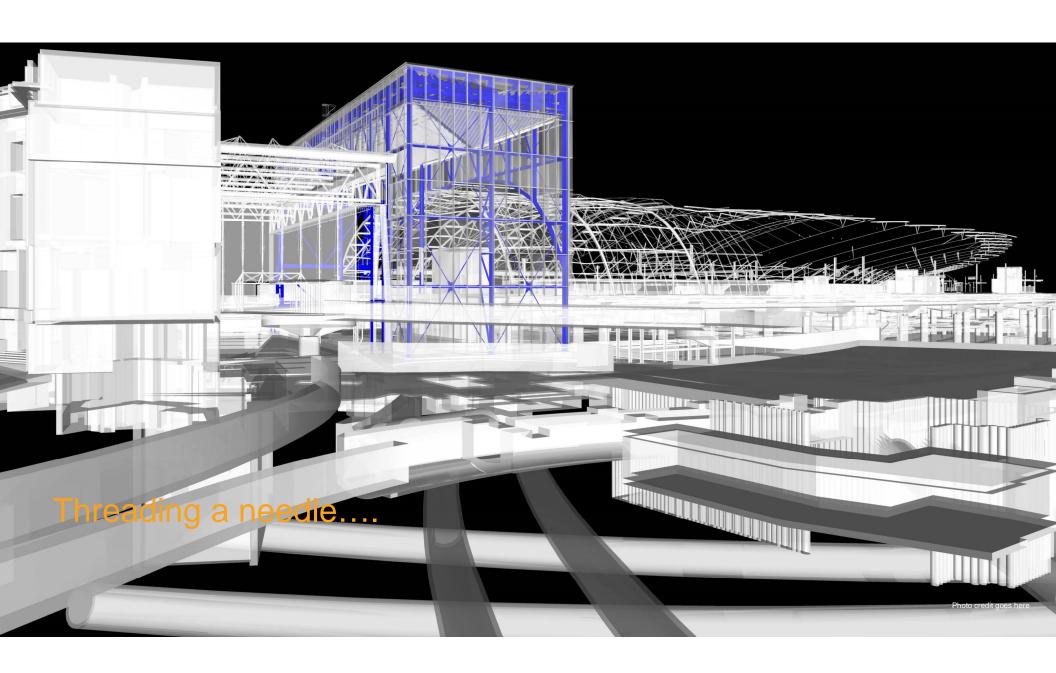
Concept Design
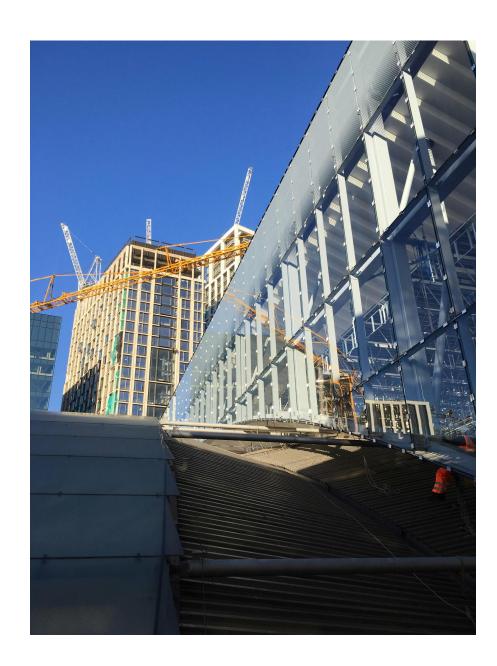
- Existing conditions modelling
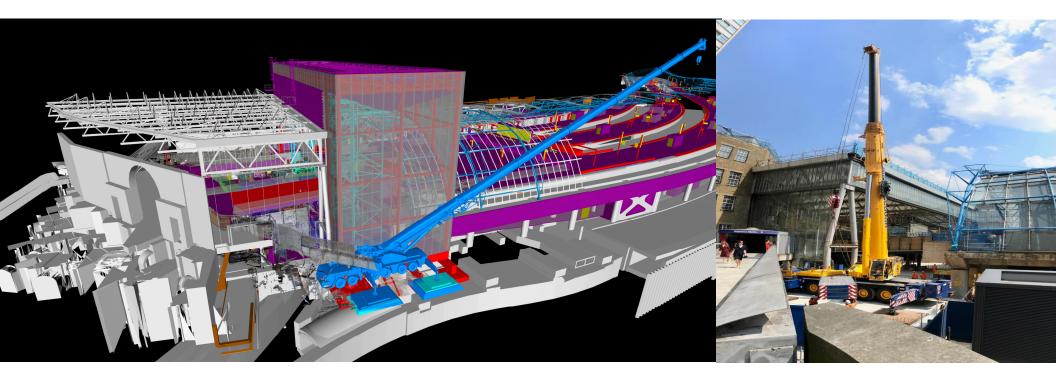 - Point cloud of adjacent structures

Threading a needle….

Why Steel?

- Minimize weight on existing structures

- Minimize number of support points

- Connection to existing steel structures
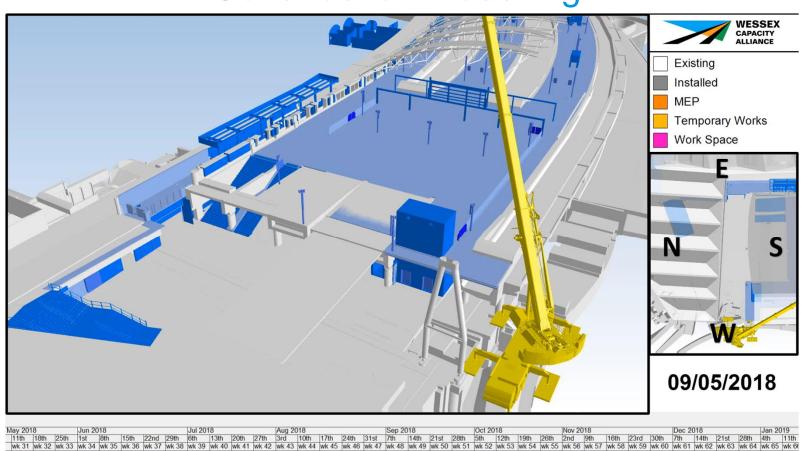
- Maximize open space for glazing and louvres

- Maximize off-site construction

Construction Modelling

Combining the construction schedule with design models

Construction Modelling

Detailed Design - Key Challenges

10+
DISCIPLINES TO COORDINATE
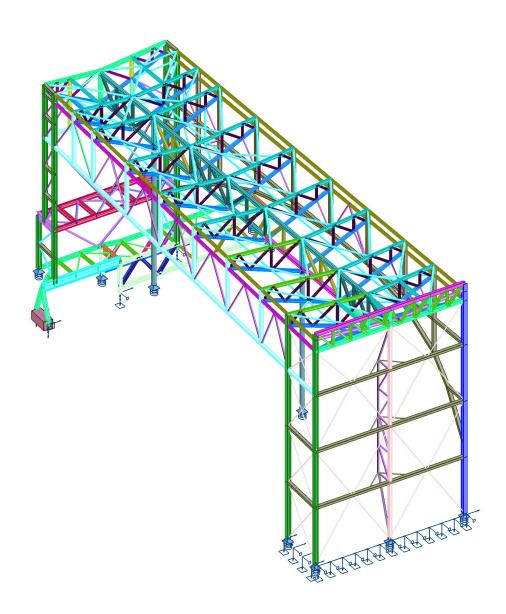
45m
SPAN OF NORTH TRUSS

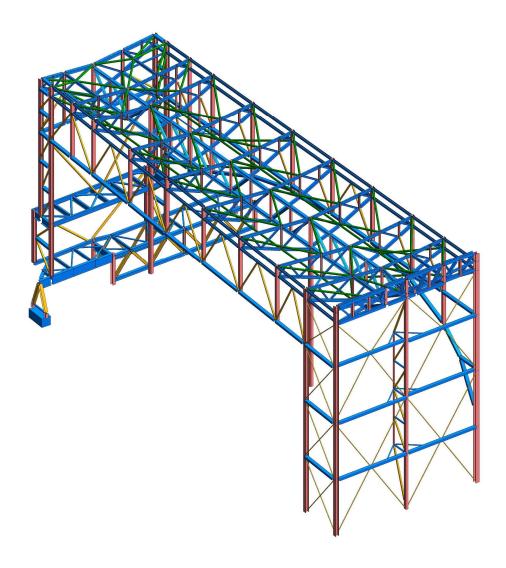**1/1000**
SWAY ALLOWANCE

12
SUPPORT POINTS

Detailed Analysis

- Several analysis models developed
  - ULS
  - SLS
  - Blast
  - Post Blast
  - Foundation Sensitivity
- Robot Structural Analysis used for analysis and design
- Results compiled into data base for connection design

Model Hand Over

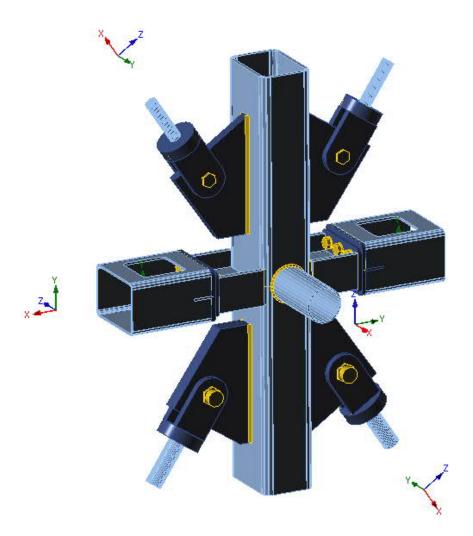- Robot model converted to IFC via. Revit to be shared with fabricator

Detailed Coordination

Weekly coordination review meetings with key design team members

All disciplines used BIM to assist with coordination

Detailed Coordination
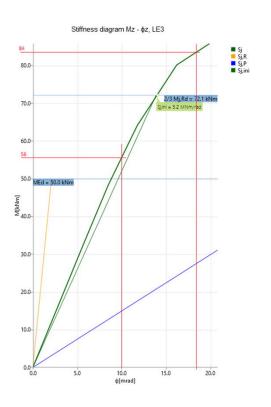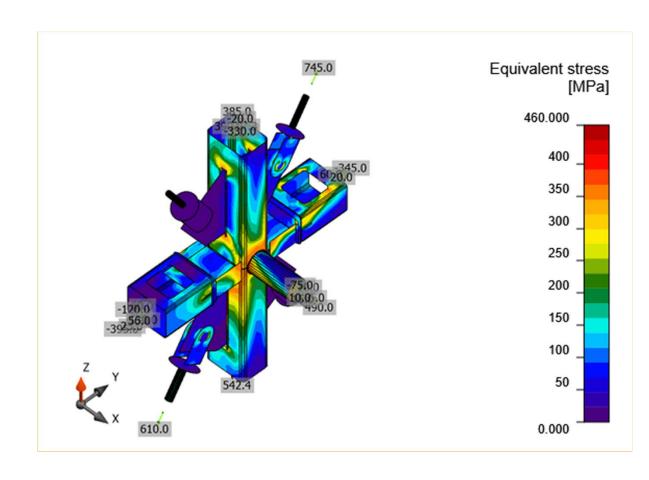
- As –Built data used to coordinate ancillary structures

Connection Design

- Architecturally exposed

- 120 year design life

- Tension only elements for MacAlloy bars

- Access holes for bolt tightening

- RHS Transoms fixed in major axis, pinned in minor axis, axially stiff

- 3 different sets of load combinations
  - ULS
  - ACC – Blast
  - ACC – Post Blast

- Non-slip connection at service for transoms

- Internal forces in upright element required to be modelled.

Connection Design

Outcomes

2,000

ELEMENTS IN
STEELWORK MODEL

150+

CONNECTION TYPES

18

MONTHS TO DESIGN
STEELWORK

6

MONTHS TO ERECT
STEELWORK

Outcomes

Lessons Learnt

KEEP IT SIMPLE

Simplify structural design as far as possible

STRENGTH vs STIFFNESS

Connection stiffness can impact on assumptions in global design model

Check sensitivity at early stage

CLASH AVOIDANCE NOT DETECTION

Use BIM as a tool not the solution

Case Study – Jakarta Velodrome

Image caption goes here

2016: Jakarta Velodrome

- Project
  - Jakarta International Velodrome (2016-2018)
- Client
  - ES Global Ltd.
- Location
  - Jakarta, Indonesia
- Key Features
  - 2000 seats
  - UCI standard timber track
  - Lightweight membrane roof

Key Challenges

400x300ft
SPAN OF ROOF

D
SEISMIC RISK CATEGORY

75%
RE-USED STEELWORK COMPONENTS
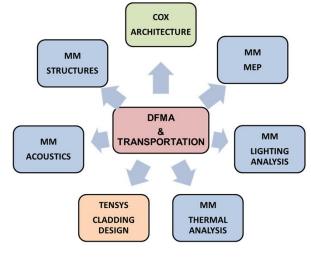
40ft
SIZE OF CONTAINER TO SHIP STEELWORK

Key Challenges
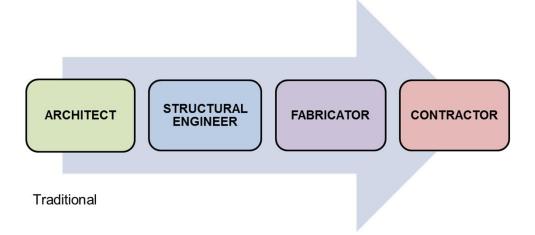
3
DESIGN CODES TO RECONCILE

3
CONTINENTS WHERE DESIGN TOOK PLACE

9
MONTHS DESIGN PROGRAMME

18
MONTHS TO CONSTRUCT

Traditional

Optimised

Fabrication – Led Design
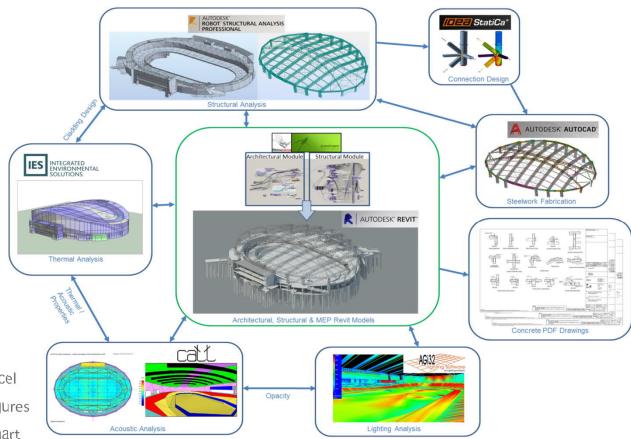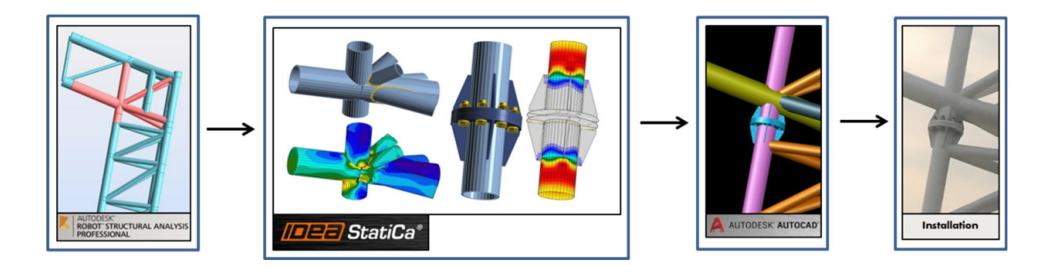
Design Workflow
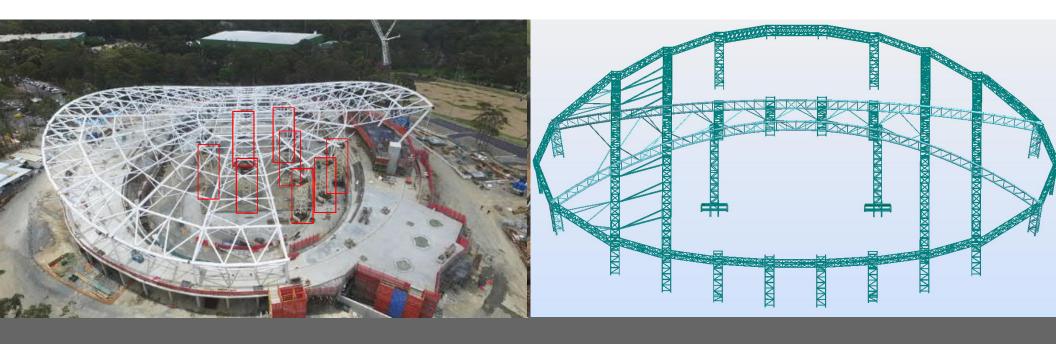
YOUR TITLE HERE

Right click on the chart for an excel spreadsheet to populate your figures and automatically update this chart

Connection Design Workflow

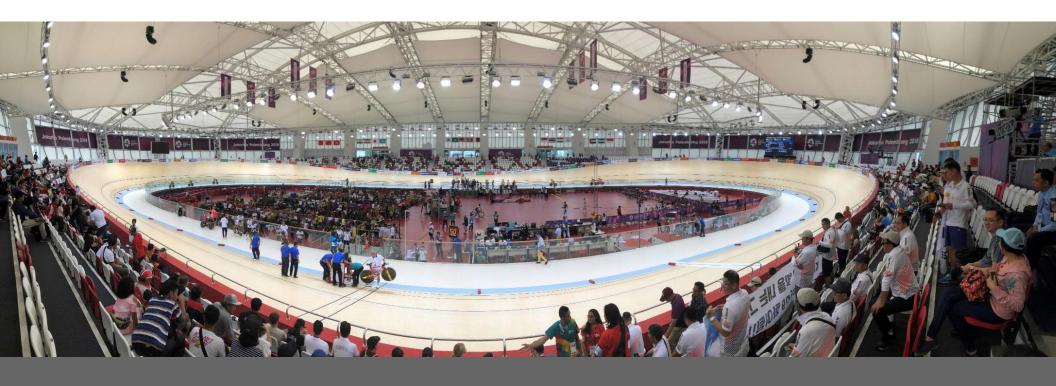Lorem ipsum dolor sit amet, consectetur adipiscing elit.

Cras lacinia interdum odio, at cursus elit sagittis lobortis.

Proin eu nisl molestie, dignissim ante ut, dictum ex. In nisi

erat, tristique ut mauris id, egestas convallis enim.

Construction Engineering

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Cras lacinia interdum odio, at cursus elit sagittis lobortis. Proin eu nisl molestie, dignissim ante ut, dictum ex.

Outcomes

6,000

ELEMENTS IN
STEELWORK MODEL

Right click on the chart for an excel
spreadsheet to populate your figures
and automatically update this chart

90

CONNECTION TYPES

Right click on the chart for an excel
spreadsheet to populate your figures
and automatically update this chart

6

MONTHS TO DESIGN
STEELWORK

Right click on the chart for an excel
spreadsheet to populate your figures
and automatically update this chart

6

WEEKS TO ERECT
STEELWORK

Right click on the chart for an excel
spreadsheet to populate your figures
and automatically update this chart

Outcomes

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Cras lacinia interdum odio, at cursus elit sagittis lobortis. Proin eu nisl molestie, dignissim ante ut, dictum ex.

Photo credit goes here

Lessons Learnt

DESIGN FOR FABRICATION

Modular sizes

Agree connection principles with contractor

Consider construction staging throughout

DUCTILITY VS. STRENGTH

Balance of minimizing size of structural elements vs. connection detailing

DEVIL IN THE DETAIL

Clear the "too difficult" pile before fabrication starts

Fully detailing Prefabricated elements led to fewer clashes on site

FUTURE = DATA SHARING

Sharing parametric scripts much more efficient than sharing models

Will need new type of quality control and change management.

CBFEM – The Background
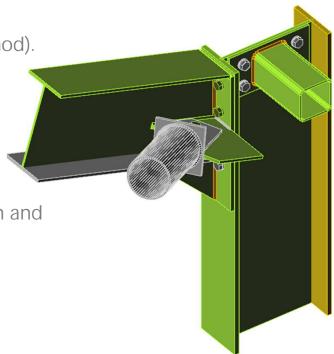
CBFEM – introduction

The method for design and code-check of steel connections and anchoring by finite elements.

All checks according to the code (same as the Component method).
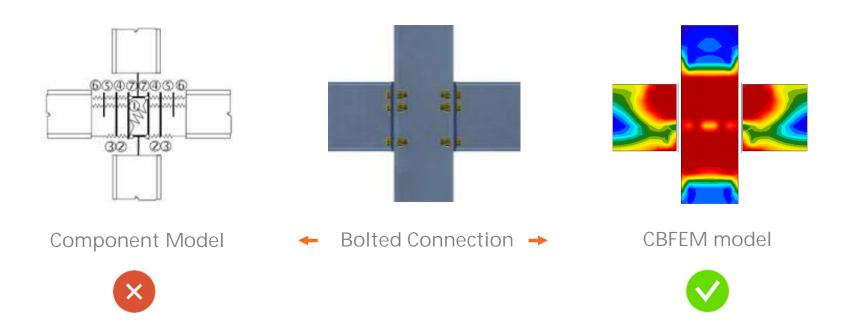
Why it was created?

Structural engineers needed a tool for quick and efficient design and code-check of steel connections and anchoring.
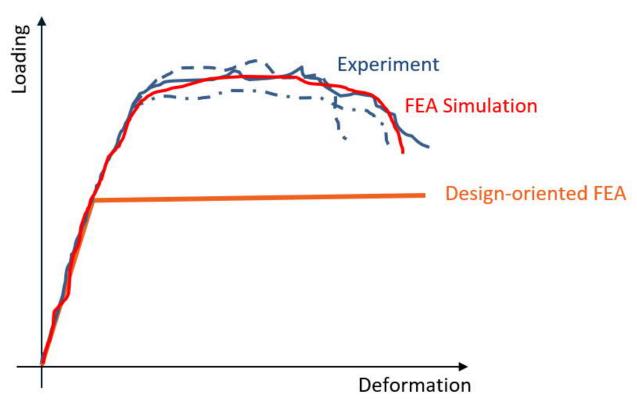
How did we invent it?

The weak point of the standard Component method is limited topology. At the same time, everybody is using finite elements for global analysis. We merged both methods in one.

Component Model

⬅ Bolted Connection ➡

CBFEM model
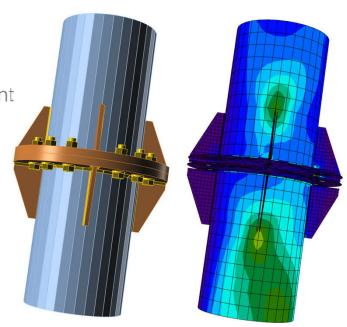
The Basis

Design-oriented FEA is optimized to deliver results relevant for code-check rather than exact simulations of behavior in extreme case.
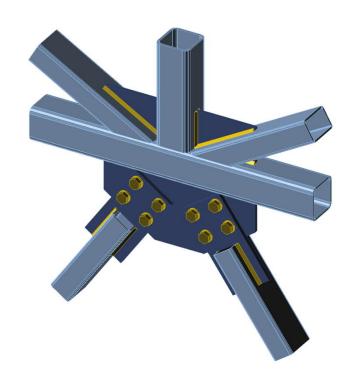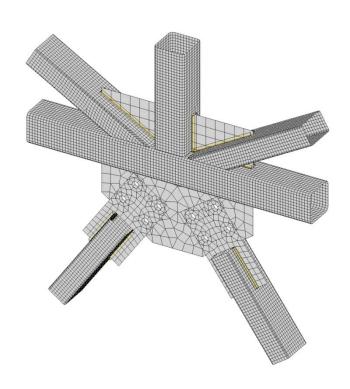
Key features of CBFEM

- FE model created for each component:

  o Member
  o Plate
  o Weld
  o Bolt/Anchor

- Analysis model created automatically from each component

  o No user input needed

- Analysis performed:

  o Material nonlinearity
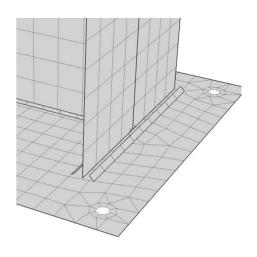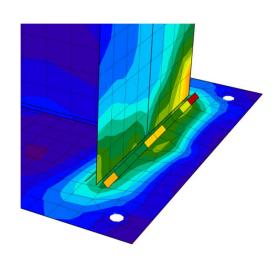 o Geometrical nonlinearity
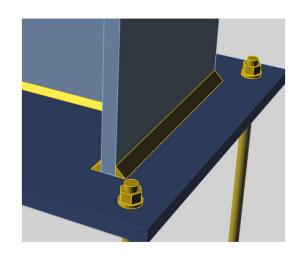
Members and Plates (CBFEM)
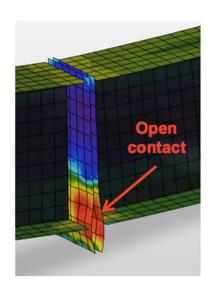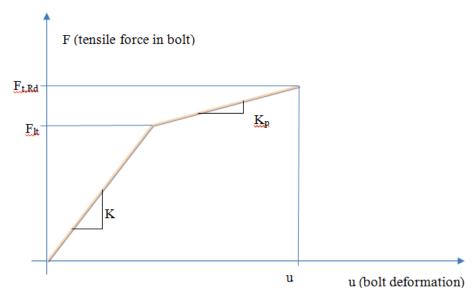

Member, plate = Shell element

Welds (CBFEM)

Weld element

- Real behavior of weld – special FE element

- Redistribution of the stress along the weld

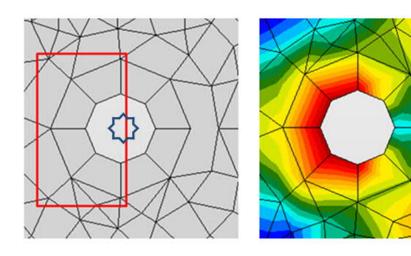- Stiffness of the weld

- Ductility

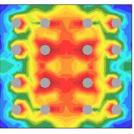# Bolts/Anchors in tension (CBFEM)

- Bolted connection = steel plates in contact + bolts

- Bolts are modeled as nonlinear springs

- Heads and nuts are connected by force interpolation constrains
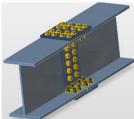
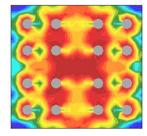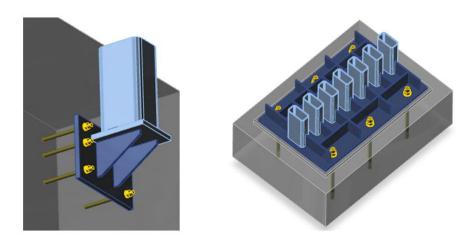# Bolts/Anchors in shear (CBFEM)

Bolts

- nonlinear springs
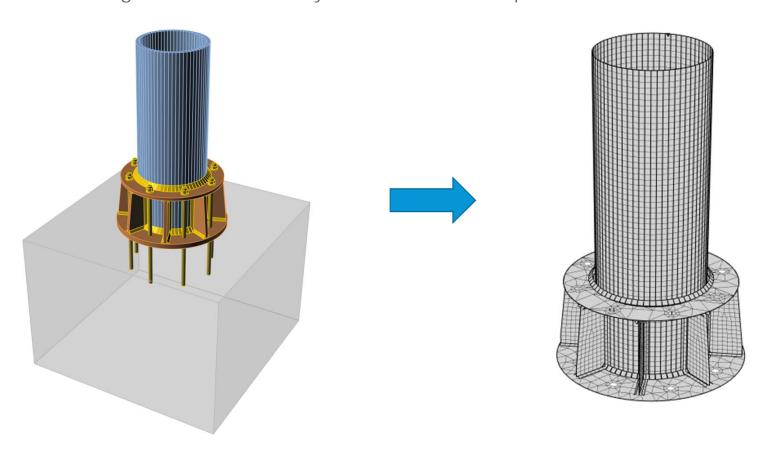
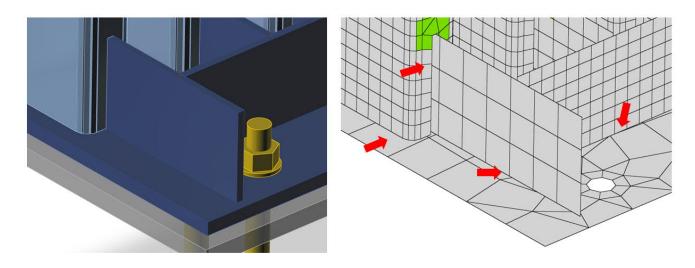- in contact with steel plate

Anchoring (CBFEM)

- Contact element between concrete and steel base plate

- Contact stress is evaluated, average stress from the effective area is checked

- Shear force is checked against friction, shear iron or bolts

Analysis model (CBFEM)

Automatic generation of the analysis model – no user input needed

Dedicated FEM solver (CBFEM)

- Majority of CAE/FEA programs have FEM solvers from early '90s

- Other industries moved faster – aircraft industry

- Mesh – no intersection between plates

- Plates are connected by interpolation constrains and weld finite elements

Credibility and Verification of CBFEM

- Tailor-made design models created in various software (Midas FEA, Atena, Abaqus)

- Live testing

- All studies published

- Three years of studies produced by two university teams

CA25 Which university? it would be great to show a little more depth to these two studies. What did they find? What were results?
Clark, Alexis, 23-Oct-19

DK5 there are a lot of studies, evyrything is summarised in our Verification book and artices on our WEB (web is mentioned further)
David Kučera, 25-Oct-19

OF1 Ondřej Fridrich, 29-Oct-19

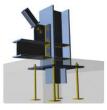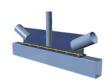# Cooperation with Universities = Verified Solution
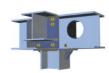
What Makes CBFEM Unique?

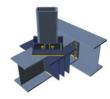- CBFEM method is robust and generally without limits in topology, design or structure loading.

CBFEM powers multiple SW tools:

- IDEA StatiCa

- HILTI PROFIS Engineering

- Advance Design Connection
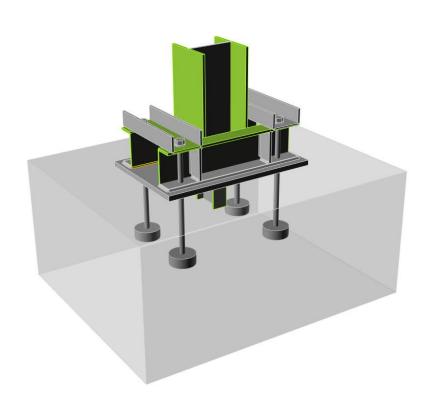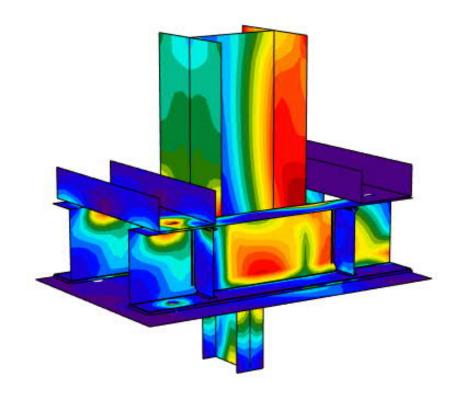

- Voestalpine Profilform

Where can I learn everything about **CBFEM**?

www.cbfem.com

Summary

Design Workflows

1. Use concept design stage to establish design parameters and assess potential solutions

2. BIM and parametric design can be used to quickly assess different options

3. Use detailed design to refine design and flush out the awkward details

4. Multiple tools – BIM, parametric design, FE analysis, clash detection, fabrication modelling

Challenges in Real Life Projects

1. Constructability should be central to design

2. Seek early contractor involvement – cannot design connections in isolation

3. All parties need to be on board with using digital design – only as good as the weakest link

4. Keep it simple – the most lightweight design may not be the best design

Use of IDEA Statica

1. Enables complex connections to be modelled quickly

2. Works best when fully integrated into the digital design process

3. Enables checks on stiffness as well as strength

CBFEM

1. Based on finite element analysis – natural extension of global finite element analysis

2. Ability to model elastic and plastic behavior

3. Enables designer to visualize interaction between components and determine "weakest link" in connection

Thank you for listening
Any Questions?