Dynamo for Engineers, Design for All

Processes that work for us

Ian Wise | Senior Engineer | Arup
Steven Brown | Engineer | Arup
Hugh Groves | Engineer | Arup

ARUP

Some context

Life on planet Arup

ARUP

Article
July 2017

Improving construction productivity

By Filipe Barbosa, Jan Mischke, and Matthew Parsons

McKinsey research finds seven levers can fix construction's productivity problem, but they require a new approach from all players. We heard from industry leaders about which barriers to change are most likely to fall first.

The McKinsey Global Institute (MGI's) *Reinventing construction: A route to higher productivity* report, released in February 2017, found that the construction industry has an intractable productivity problem. While sectors such as retail and manufacturing have reinvented themselves, construction seems stuck in a time warp. Global labor-productivity growth in construction has averaged only 1 percent a year over the past two decades, compared with growth of 2.8 percent for the total world economy and 3.6 percent in manufacturing (exhibit).

RELATED

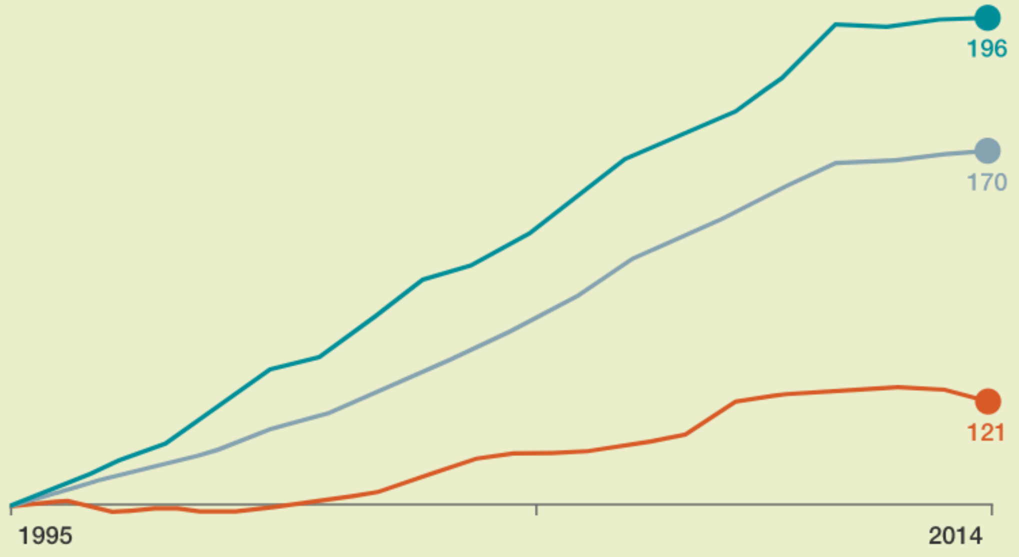
Global Infrastructure Initiative

Convening global leaders in infrastructure and capital projects in pursuit of new solutions

Learn more

ARUP

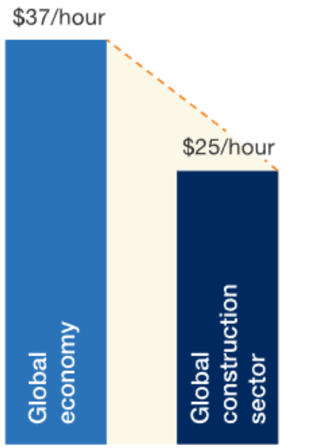
Real gross value added per hour worked, index of 2005 $: 100 = 1995



Source: GGCD-10; national statistical agencies of Turkey, Malaysia, and Singapore; OECD, Rosstat; US Bureau of Economic Affairs; US Bureau of Labor Statistics; WIOD; World Bank; McKinsey Global Institute analysis

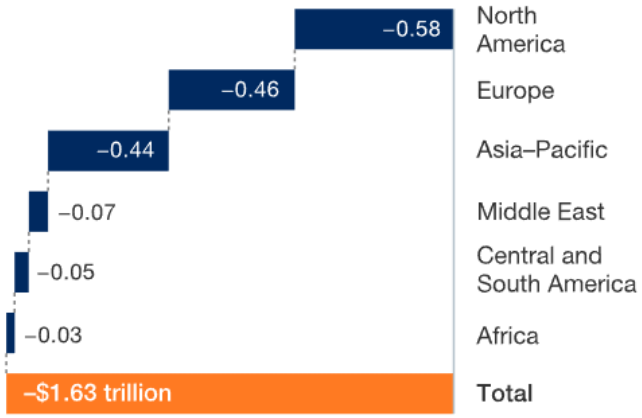
McKinsey&Company

Productivity gap =
$1.63 trillion



Average value added by employees per hour worked[1]

Economic value lost as a result of the gap,[2]
by region, $ trillion



[1]2015 data in real 2005 dollars.
[2]Assumes construction productivity catches up with total economy productivity and current workers are reemployed at the total economy productivity rate.

McKinsey&Company

ARUP

Article
June 2016

Imagining construction's digital future

By Rajat Agarwal, Shankar Chandrasekaran, and Mukund Sridhar

The industry needs to change; here's how to manage it.

The construction industry is ripe for disruption. Large projects across asset classes typically take 20 percent longer to finish than scheduled and are up to 80 percent over budget (Exhibit 1). Construction productivity has actually declined in some markets since the 1990s (Exhibit 2); financial returns for contractors are often relatively low—and volatile.

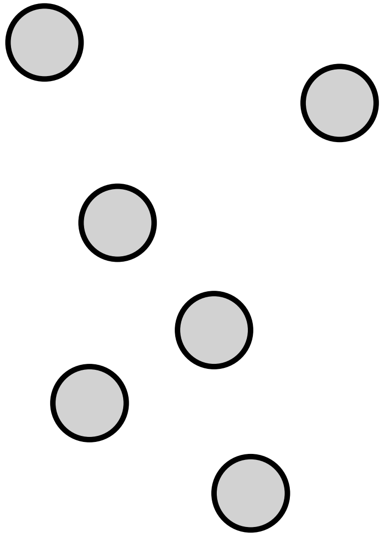
[1]Based on a set of metrics to assess digitization of assets (8 metrics), usage (11 metrics), and labor (8 metrics).

[2]Information and communications technology.

Source: AppBrain; Bluewolf; Computer Economics; eMarketer; Gartner; IDC Research; LiveChat; US Bureau of Economic Analysis; US Bureau of Labor Statistics; US Census Bureau; McKinsey Global Institute analysis

McKinsey&Company

Some things are very hard and demand new approaches



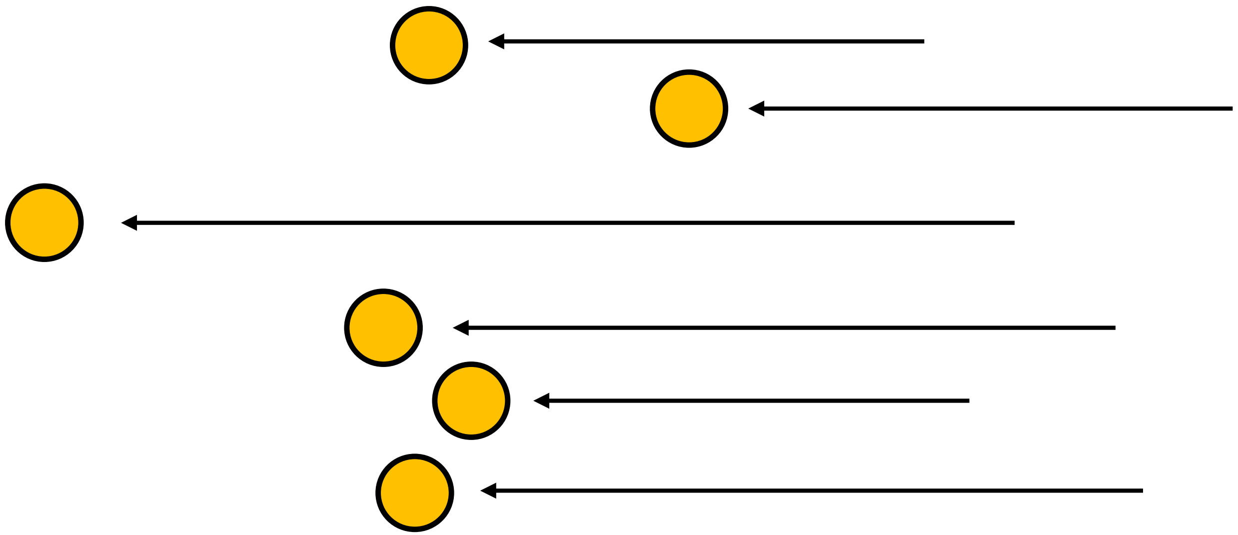
Child’s play

Manageable

Impossible

ARUP

We can make them practical and achievable

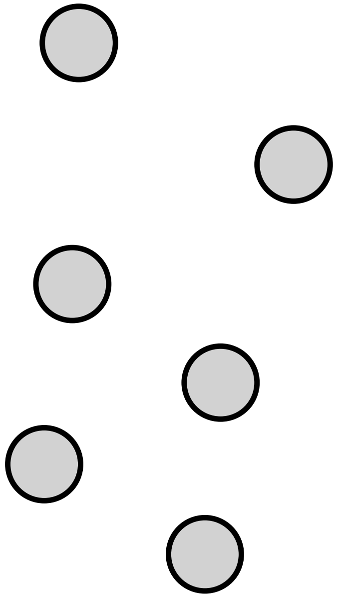


Child's play

Manageable

Impossible

ARUP



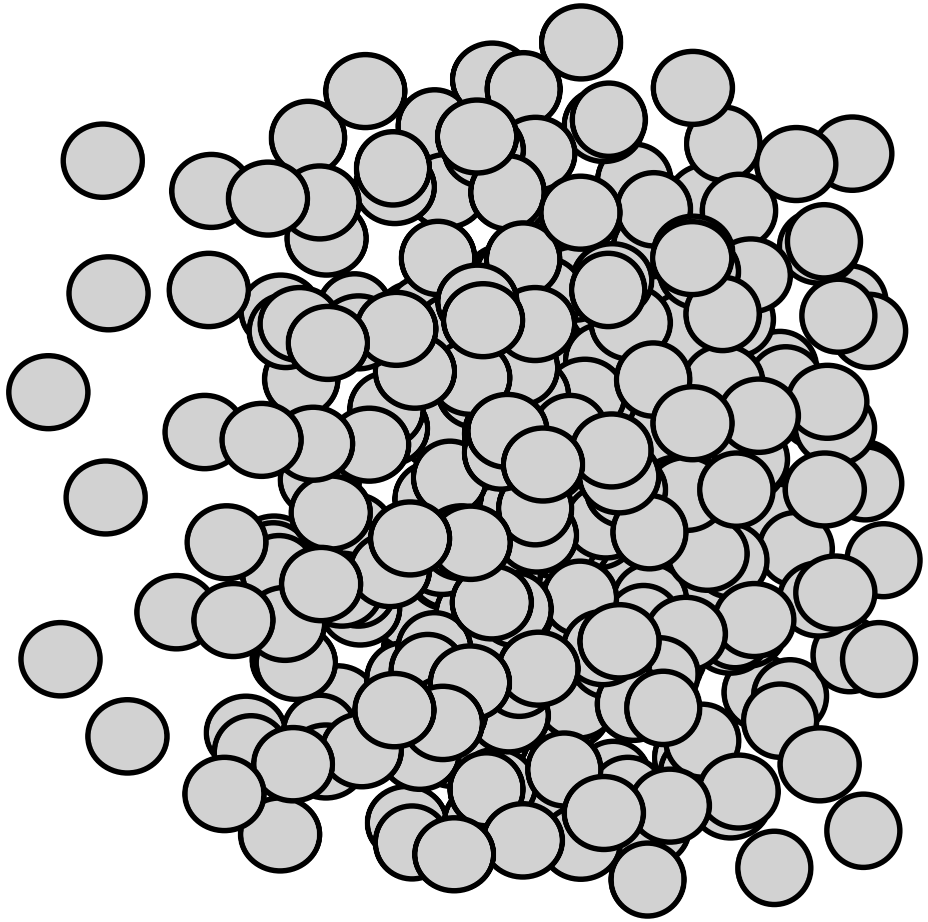
But what about the things that we can already do?

Child's play

Manageable

Impossible

ARUP

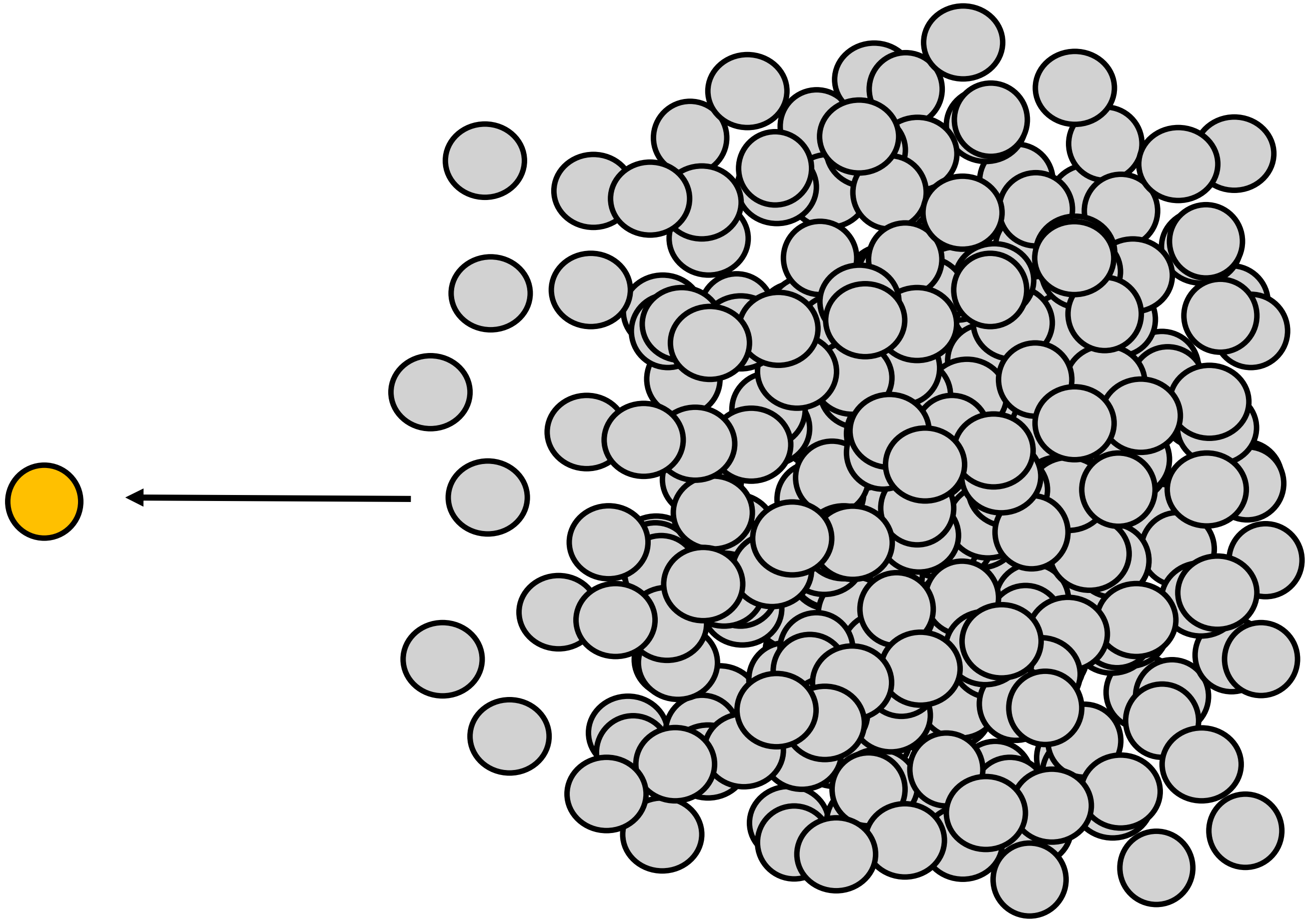


Because there are a lot of those?

Child's play

Manageable

Impossible



How easy can we make them?

Child's play | Manageable | Impossible

Current practice

And why we want to change it...


United Kingdom
Country Boundary
Road
River
Sovereign State Capital
Country Capital
City or Town
NORTH ATLANTIC OCEAN
Norwegian Sea
SHETLAND ISLANDS
Lerwick
ORKNEY ISLANDS
Kirkwall
Thurso
Stornoway
Lewis with Harris
The Minch
Ullapool
North Uist
South Uist
Skye
Inverness
Loch Ness
Rum
HEBRIDES
SCOTLAND
Fort William
Dundee
Perth
Mull
Oban
Islay
Glasgow
Edinburgh
Tweed
Ayr
Arran
Dumfries
Stranraer
North Channel
Londonderry
NORTHERN IRELAND
Belfast
Lough Neagh
Sligo
Lough Allen
Dundalk
Westport
Drogheda
Lough Ree
Galway
Dublin
IRELAND
Shannon
Lough Derg
Limerick
Tralee
Waterford
Wexford
Cork
Saint George's Channel
Newcastle upon Tyne
Carlisle
Sunderland
Workington
Middlesbrough
Scarborough
Douglas
Barrow-in-Furness
Isle of Man (Crown Dependency)
ENGLAND
York
Kingston upon Hull
Blackpool
Bradford
Leeds
Preston
Irish Sea
Grimsby
Manchester
Sheffield
Liverpool
Holyhead
Anglesey
Chester
Caernarfon
Stoke-on-Trent
Trent
Derby
Nottingham
King's Lynn
Norwich
Shrewsbury
Wolverhampton
Leicester
Peterborough
Birmingham
Coventry
Cambridge
Aberystwyth
Severn
Wye
Ipswich
Northampton
Stratford-upon-Avon
Hereford
Fishguard
WALES
Gloucester
Luton
Oxford
Swansea
Newport
London
Southend-on-Sea
Thames
Cardiff
Bristol
Bath
Reading
Canterbury
Dover
Bristol Channel
Strait of Dover
Calais
Southampton
Brighton
Hastings
Exeter
Bournemouth
Portsmouth
Plymouth
Torbay
Weymouth
Isle of Wight
English Channel
Penzance
ISLES OF SCILLY
Alderney (Crown Dependency)
FRANCE
Sea

ARUP

Spreadsheets
Data. Output.

- Calculations
- Specifications
- Drawings

ARUP

So much data…

ARUP

So many places!

Spreadsheets

Data. Output.

Where does the data go after this

?

ARUP


Nowhere

Spreadsheets

Messy data that goes nowhere.

Is this really what we want ?

Not.

Not. Even.

Not. Even. Close.

Technology advances

So should we…

ARUP

*"It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is **most adaptable to change**."*

- Charles Darwin.

ARUP

"So why do we insist on doing things the 'old' way?"

- Us.

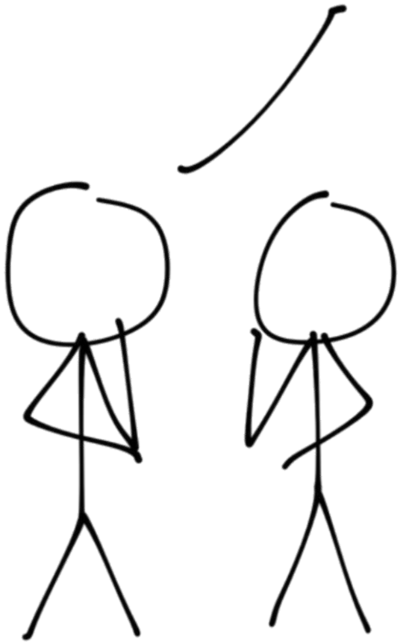
ARUP


LANXESS arena
RheinEnergie
Start
RheinEnergie


LANXESS arena
RheinEnergie
Start
RheinEnergie
Calculating...
Calculating...
Calculating...
Calculating...
Calculating...


VEHICLE WASH
VEHICLE QUALITY CONFIRMATION

WHAT IF...



ARUP

Creating

A toolmakers mentality...

ARUP

*"The point is that I don't design stuff for **myself**. I'm a toolmaker. I design things that **other people** want to use."*

- Robert Moog.

ARUP

Spreadsheets

Messy data that goes nowhere.

Is this really what we want ?

ARUP

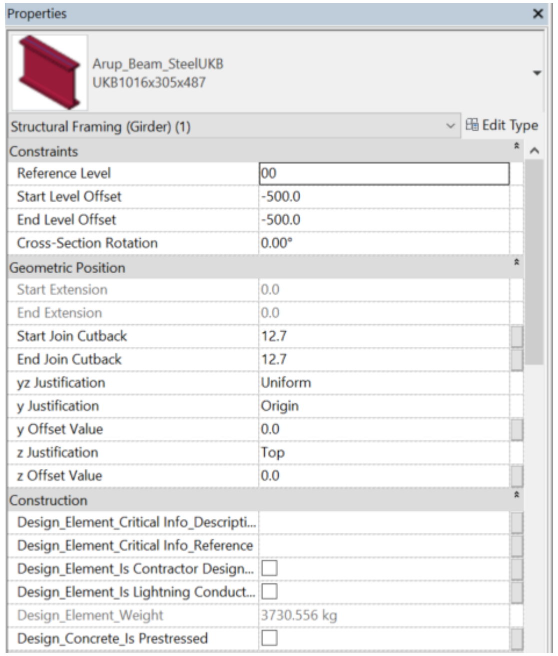
"Why don't we use the data where it is hosted?"

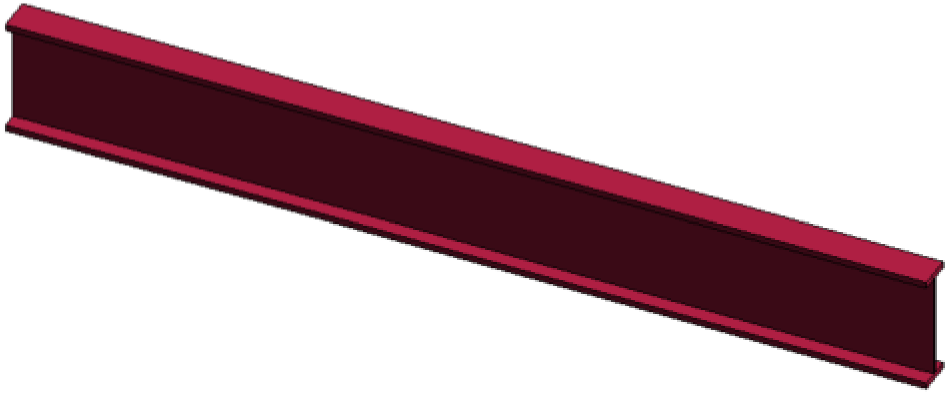
- Us.

ARUP

A single data
environment

ARUP

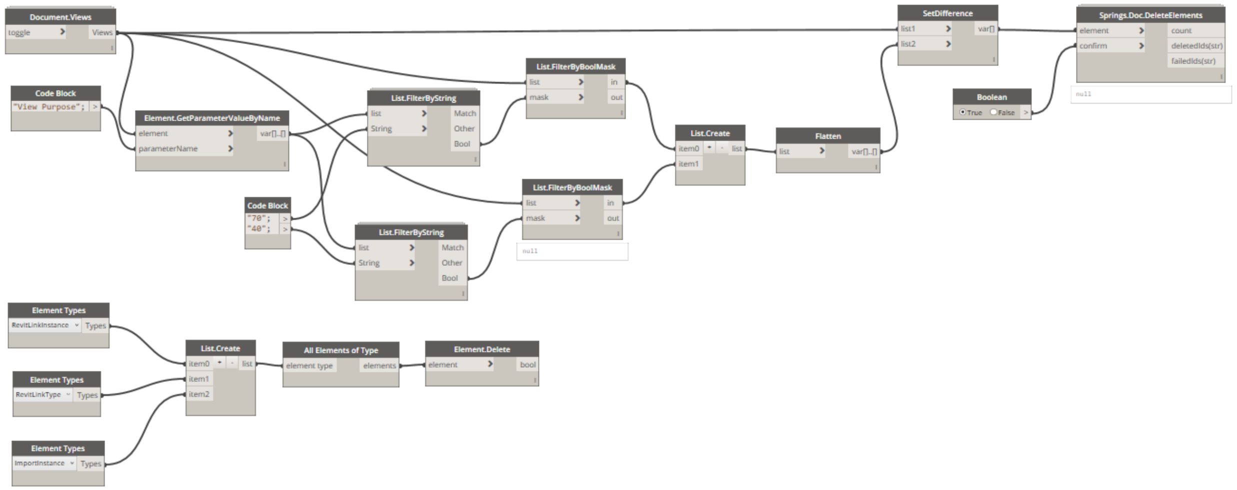




Embedded parameters for intelligent delivery

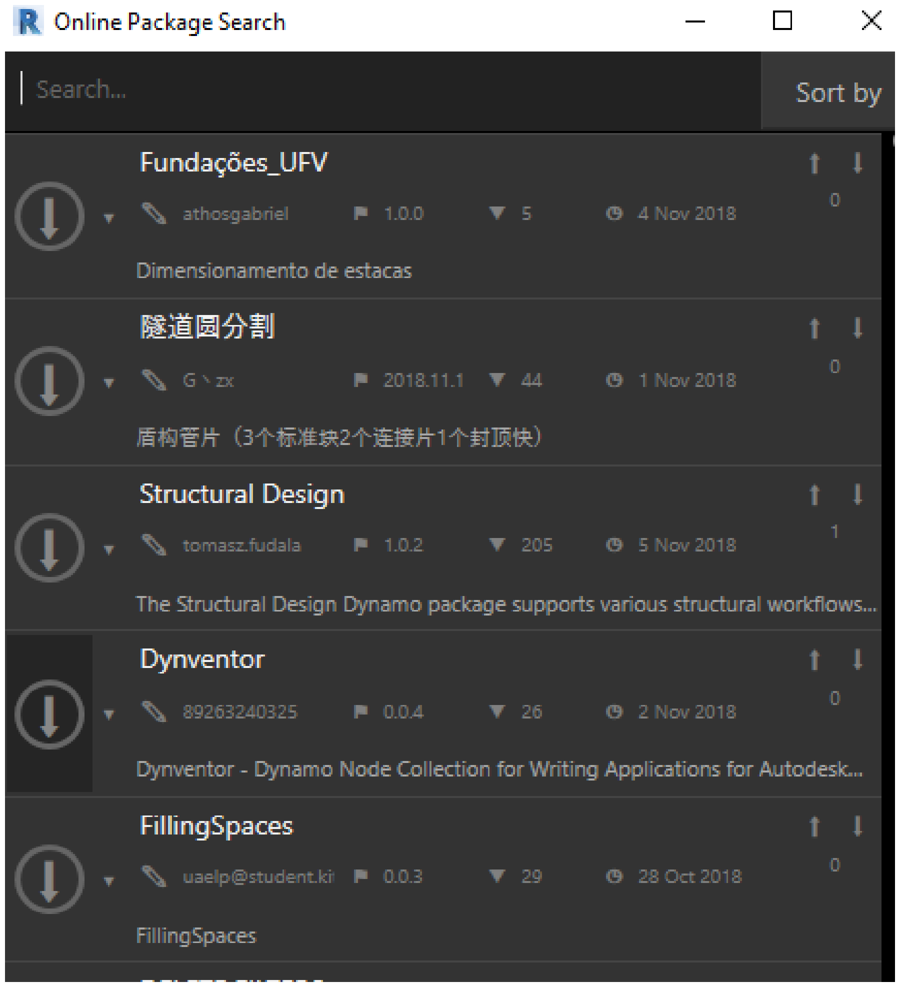
A single digital tool

ARUP

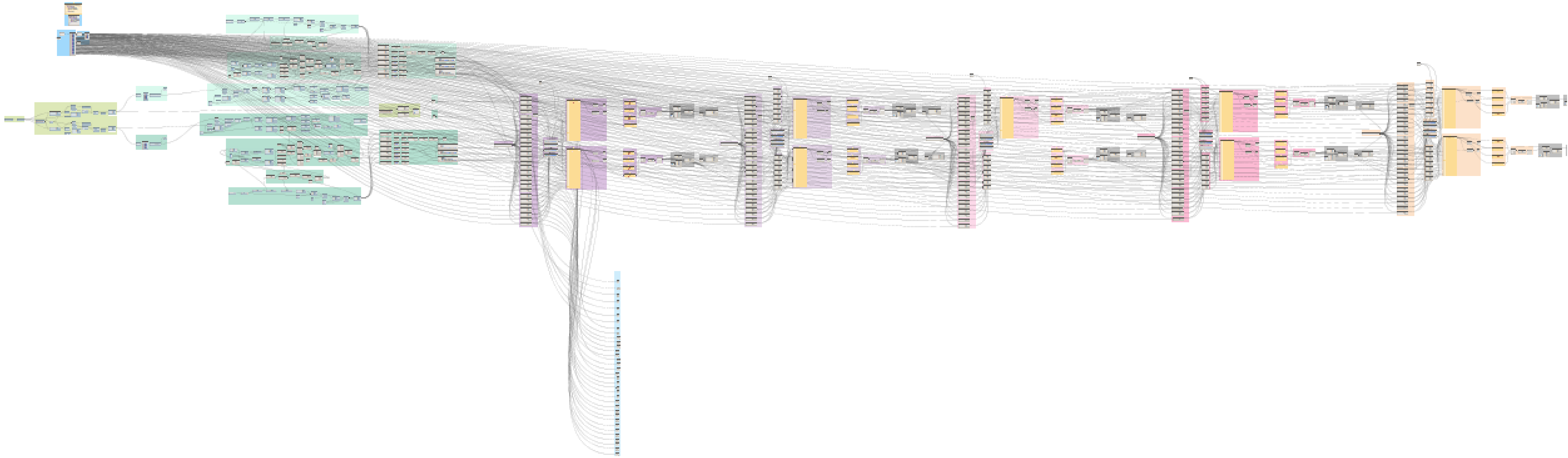


Read and write parameters for integrated calculation

ARUP



Libraries written by other people



Parametric spaghetti

ARUP

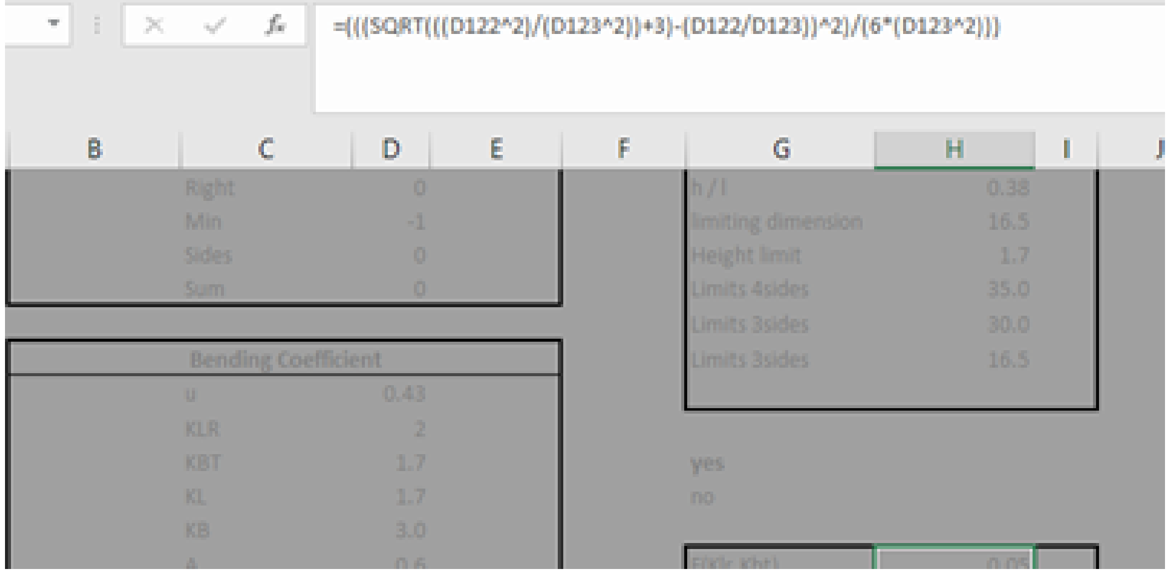
Useful tools

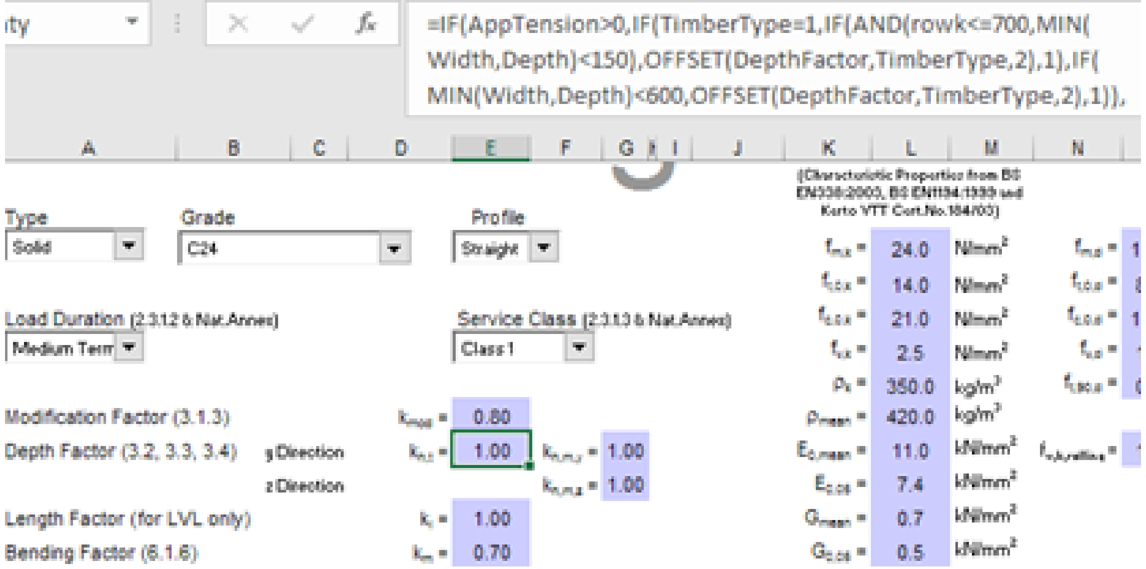
We made some…


United Kingdom
Country Boundary
Road
River
Sovereign State Capital
Country Capital
City or Town
London is the capital of both the country of England and the sovereign state of the U.K.
0 50 100 KM
0 50 100 Miles
© 2018 Geology.com
Norwegian Sea
SHETLAND ISLANDS
North Sea
Lerwick
NORTH ATLANTIC OCEAN
ORKNEY ISLANDS
Kirkwall
Thurso
Stornoway
Lewis with Harris
The Minch
Ullapool
North Uist
South Uist
Skye
Inverness
Loch Ness
Aberdeen
SCOTLAND
Rum
HEBRIDES
Fort William
Dundee
Perth
Saint Andrews
Mull
Oban
Kirkcaldy
Islay
Glasgow
Edinburgh
Tweed
Ayr
Arran
North Sea
Dumfries
Stranraer
North Channel
Newcastle upon Tyne
Sunderland
Carlisle
Londonderry
Belfast
NORTHERN IRELAND
Lough Neagh
Workington
Middlesbrough
Scarborough
Sligo
ENGLAND
Douglas
Barrow-in-Furness
York
Kingston upon Hull
Lough Allen
Dundalk
Isle of Man (Crown Dependency)
Westport
Drogheda
Blackpool
Preston
Bradford
Lough Ree
Irish Sea
Galway
Dublin
Liverpool
Holyhead
Anglesey
Chester
Caernarfon
IRELAND
Shannon
Lough Derg
Shrewsbury
Wolverhampton
Limerick
Tralee
Waterford
Wexford
Aberystwyth
Severn
Wye
Cork
Fishguard
Hereford
Saint George's Channel
WALES
Swansea
Newport
Cardiff
Bristol
Bath
Reading
Bristol Channel
Southampton
Brighton
Hastings
Calais
Strait of Dover
Exeter
Bournemouth
Portsmouth
Weymouth
Isle of Wight
Plymouth
Torbay
English Channel
Penzance
Alderney (Crown Dependency)
ISLES OF SCILLY
FRANCE

ARUP

???


=(((SQRT(((D122^2)/(D123^2))+3)-(D122/D123))^2)/(6*(D123^2)))
B C D E F G H I J
Right 0
Min -1
Sides 0
Sum 0
Bending Coefficient
u 0.43
KLR 2
KBT 1.7
KL 1.7
KB 3.0
h / l 0.38
limiting dimension 16.5
Height limit 1.7
Limits 4sides 35.0
Limits 3sides 30.0
Limits 3sides 16.5
yes
no


=IF(AppTension>0,IF(TimberType=1,IF(AND(rowk<=700,MIN(
Width,Depth)<150),OFFSET(DepthFactor,TimberType,2),1),IF(
MIN(Width,Depth)<600,OFFSET(DepthFactor,TimberType,2),1)),
A B C D E F G H I J K L M N
Type
Solid
Grade
C24
Profile
Straight
Load Duration
Medium Term
Service Class
Class 1
Modification Factor (3.1.3) 0.80
Depth Factor (3.2, 3.3, 3.4) 1.00 1.00 1.00
y Direction
z Direction
Length Factor (for LVL only) 1.00
Bending Factor (6.1.6) 0.70
24.0 N/mm²
14.0 N/mm²
21.0 N/mm²
2.5 N/mm²
350.0 kg/m³
420.0 kg/m³
11.0 kN/mm²
7.4 kN/mm²
0.7 kN/mm²
0.5 kN/mm²

ARUP

BACS

RIYADH METRO PROJECT

Bechtel, Almabani & CCC Civil Works JV

Sub-Contractor

Arup Riyadh Metro Limited 13 Fitzroy Street London W1T 4BQ England	ARUP

Riyadh Metro Project
Package 1

WP12 Deep Stations

Spreadsheet Verification Report - Structures

Document No. **M-BAR-000DS0-CB00-ECA-000008**
Document Status: **For Review**

Document Submittal History:

Rev.:	Date:	Doc Status:	Prepared (Sub-Contractor)	Checked (Sub-Contractor)	Approved (Sub-Contractor)
00A	02-JUN-17	For Information	Anfas Thowfeek	Tim Worsfold	John Batchelor
	Signatures:			TWorsfold	JBatchelor

Note: All changes from the previous revision have a line to the left of the text.

Document Review Status	Date:	Name:
	A - Reviewed; Work may proceed	
	B - Reviewed with comments; Revise and resubmit; Work may proceed subject to incorporation of comments	
	C - Objection - Revise and resubmit; Work may not proceed	
	D – Rejected	
	E - Review not required; Work may proceed	

74.74% 1 (1 of 567)

1 (1 of 567)

ARUP

Error prone

Difficult to review

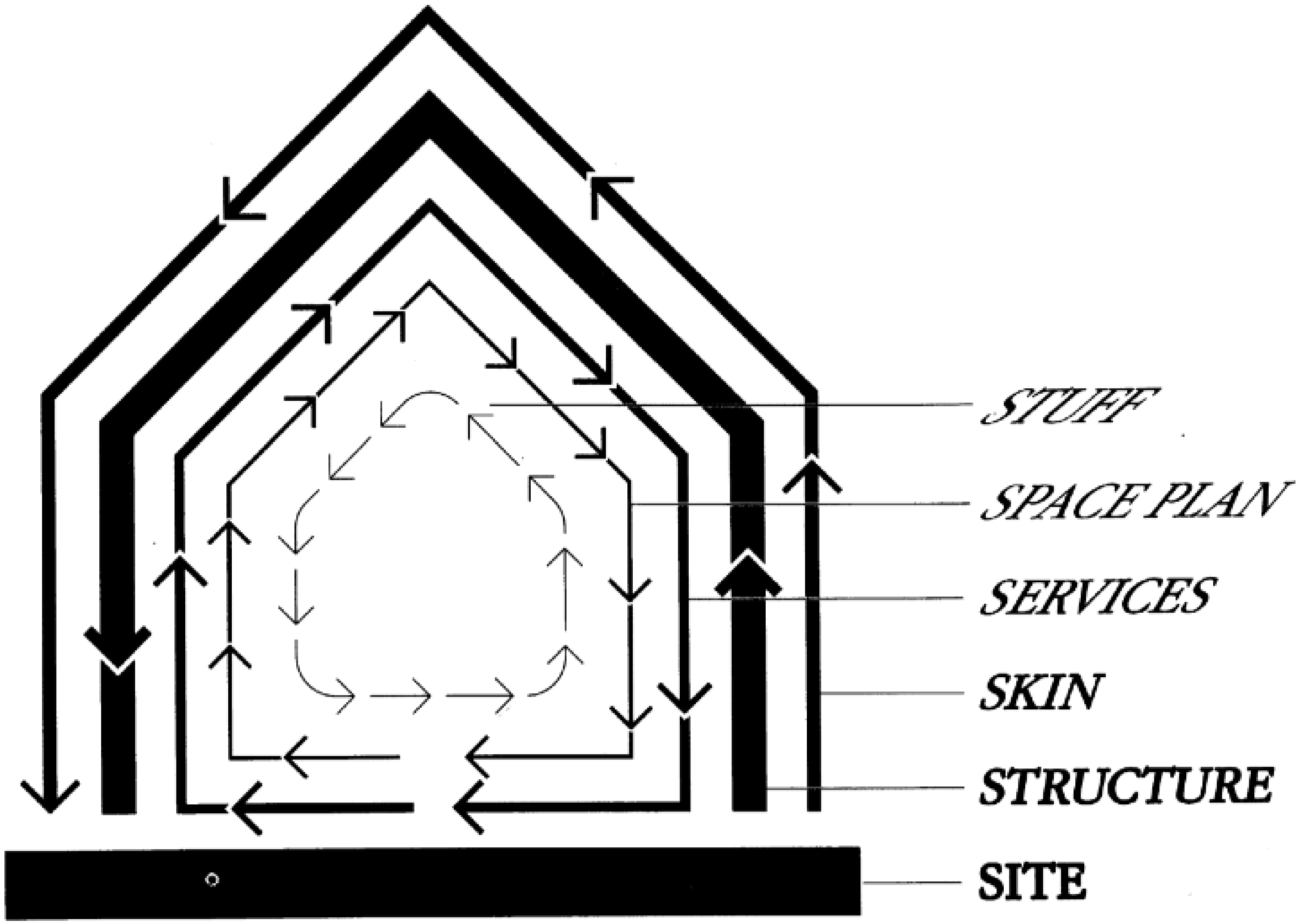
ARUP

Never re-used

ARUP


Your scientists were so preoccupied with whether
or not they could that they didn't stop to think if they should.

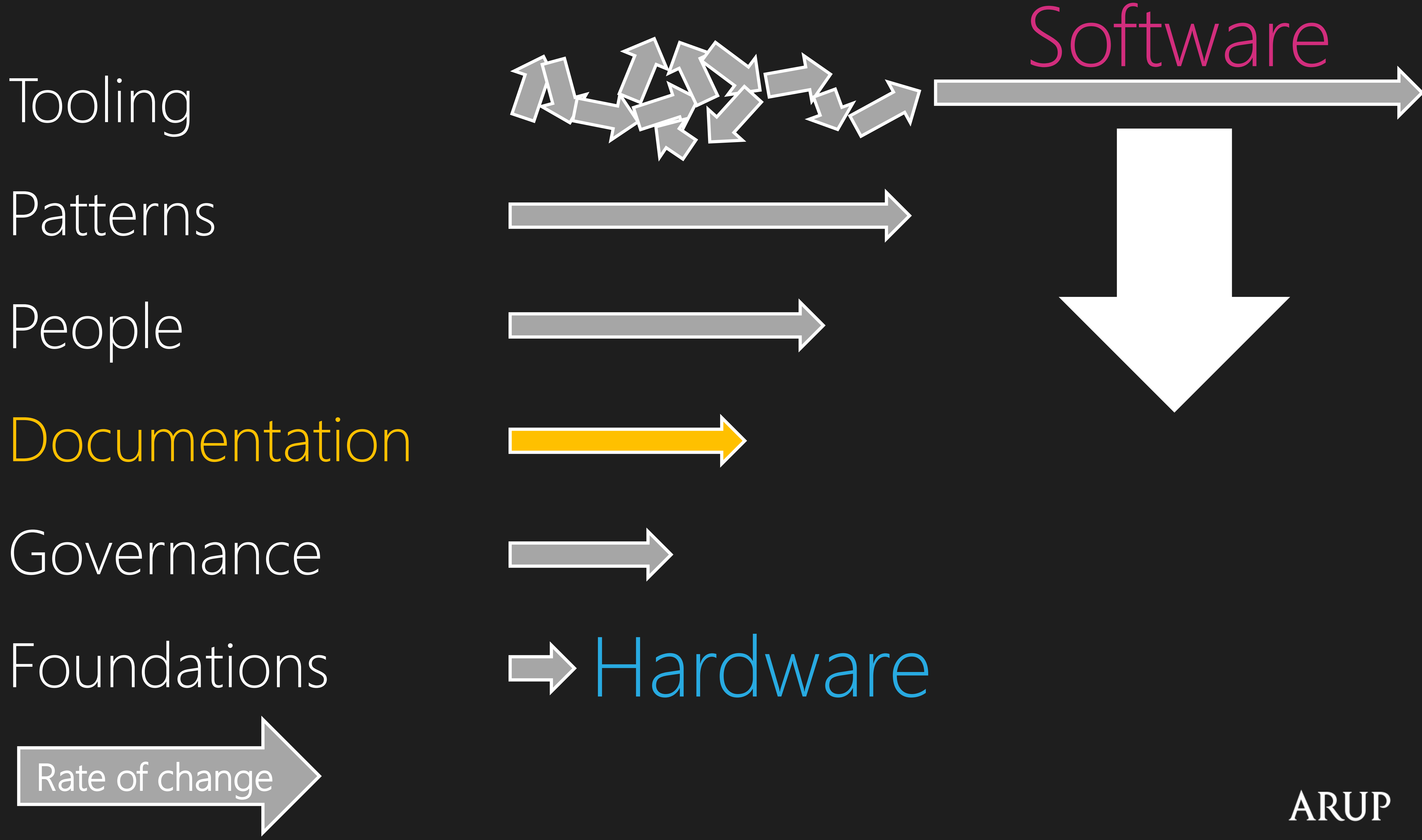

Simone Giertz



Change can be an issue

Fast learns,
slow remembers.

ARUP


Software
Tooling
Patterns
People
Documentation
Governance
Foundations
Hardware
Rate of change
ARUP

```
AddSubHeader("Inputs", false);
DeclareInput("d_w", d_w, "mm", "***EC3.GB.d_w***");
DeclareInput("e_c", e_c, "mm", "***EC3.GB.e_c***");
DeclareInput("e_p", e_p, "mm", "***EC3.GB.e_p***");
DeclareInput("m", m, "mm", "***EC3.GB.m***");
DeclareInput("t_f", t_f, "mm", "***EC3.GB.t_f***");
DeclareInput("Sigma_leff", Sigma_leff, "mm", "***EC3.GB.Sigma_l_eff***");
DeclareInput("f_y", f_y, "MPa", "***EC3.f_y***");
DeclareInput("gamma_M0", gamma_M0, "", "***EC3.gamma_M0***");

AddSubHeader("Calculation", false);
CalcVariable("n", "min(e_c, e_p, 1.25 * m)", "mm");
CalcVariable("e_w", "d_w / 4", "mm");

TStubPlasticMomentResistance calc_TStubPlasticMomentResistance = new TStubPlasticMomentResistance(t_f, Sigma_leff, f_y, gamma_M0, 1);
if (SubCalculationValid("calc_M_pl_1_Rd", calc_TStubPlasticMomentResistance))
    AddVariable("M_pl_1_Rd", calc_TStubPlasticMomentResistance.Result, "Nmm", "***EC3.GB.TStubPlasticMomentResistance***");
else
    return;

CalcVariable("F_T_1_Rd", "((8 * n - 2 * e_w) * M_pl_1_Rd) / ((2 * m * n) - (e_w * (m + n)))", "N", "***EC3.GB.TStubMode1***");

ConvertVariable("F_T_1_Rd", "kN", 1.0 / 1000.0);

AddResult(V("F_T_1_Rd"));
```

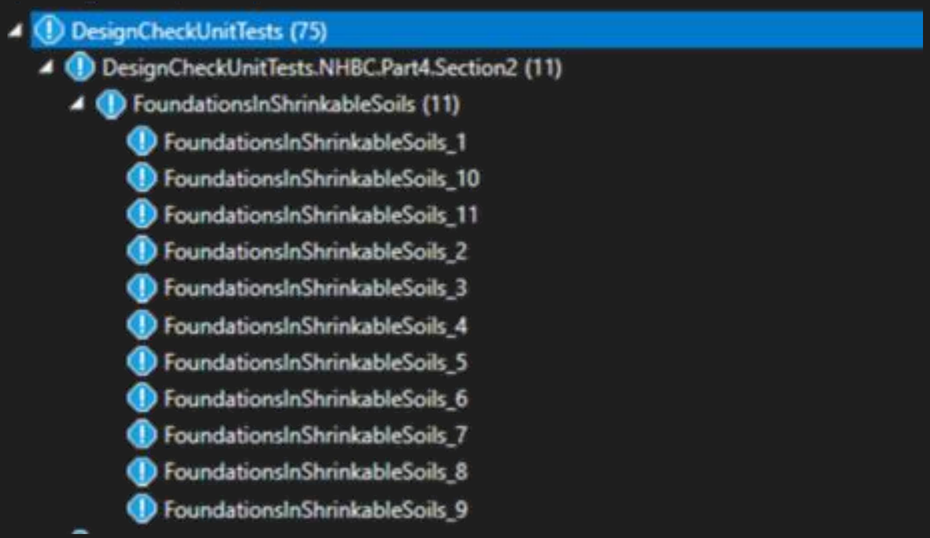
Code the calculations

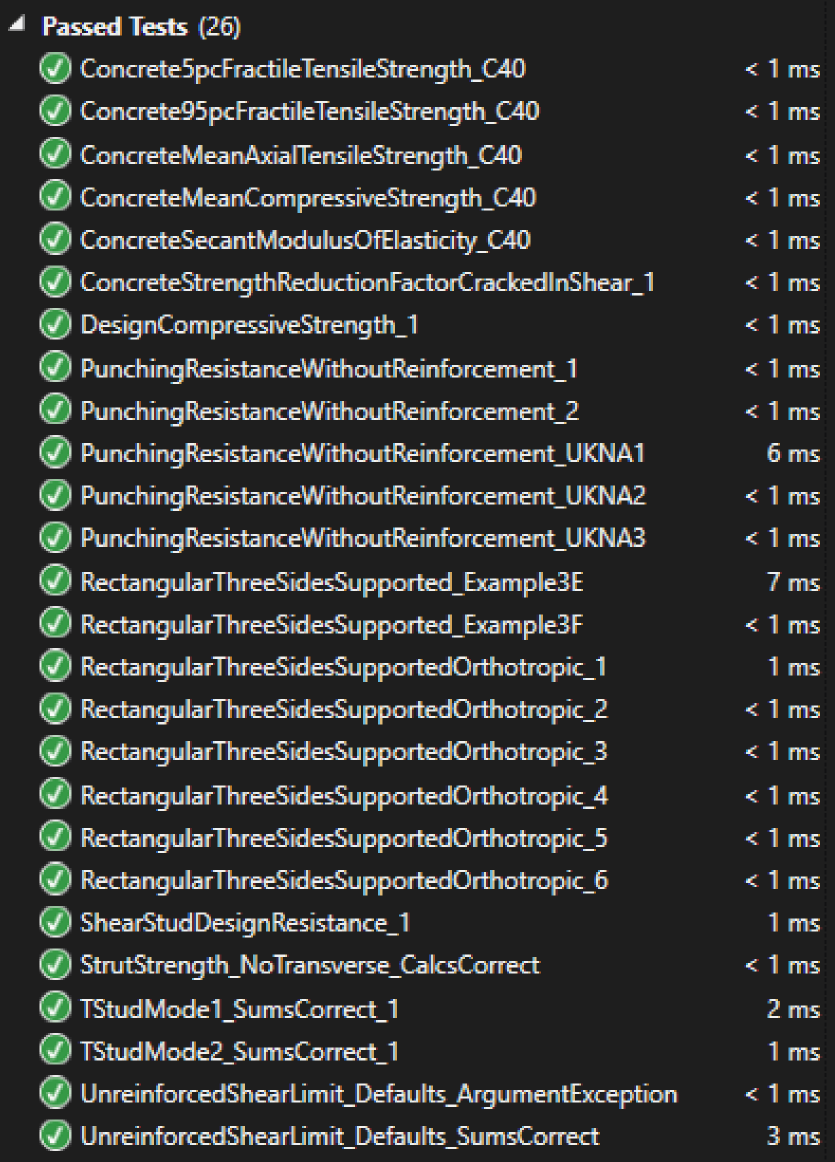
ARUP

Easy to read…

ARUP

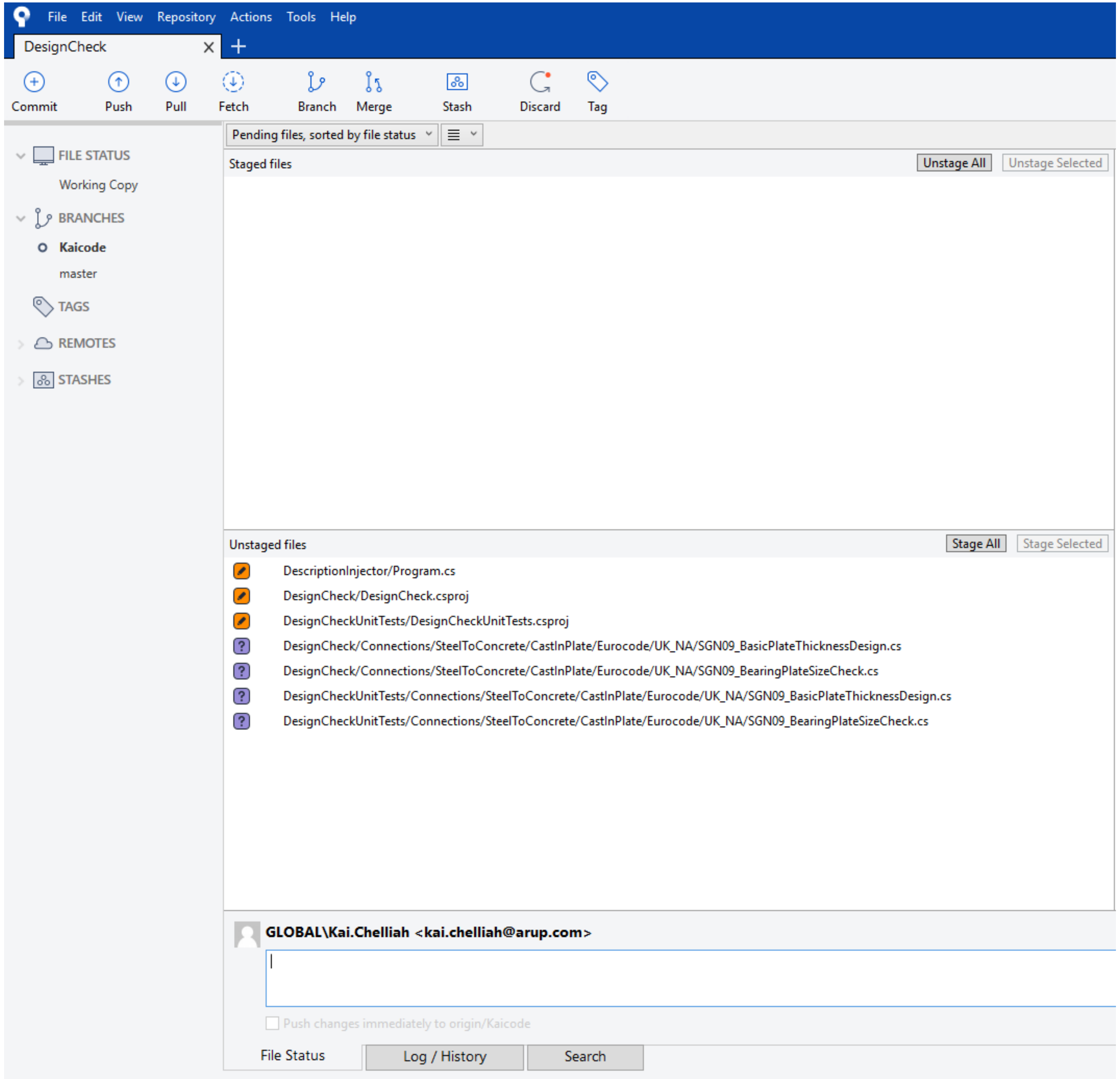
Honestly





Write unit tests

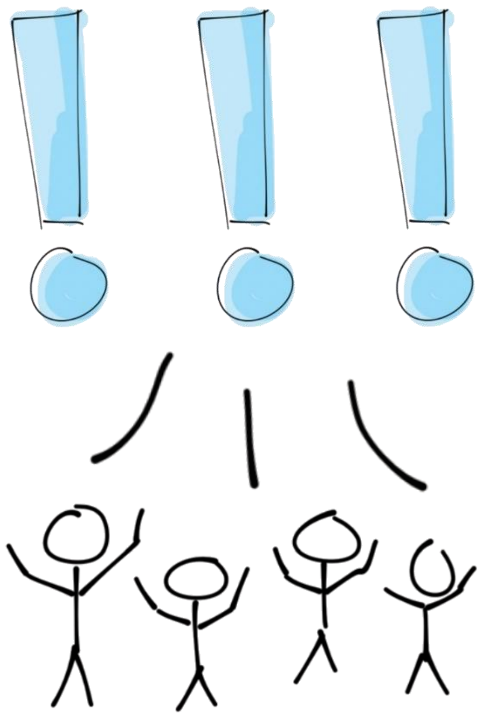
ARUP



Centralise your versioning and quality control

ARUP

No fear of losing your work



ARUP

But how do you feed it information?

ARUP

Useful tools

We made some...

Arup Cardiff

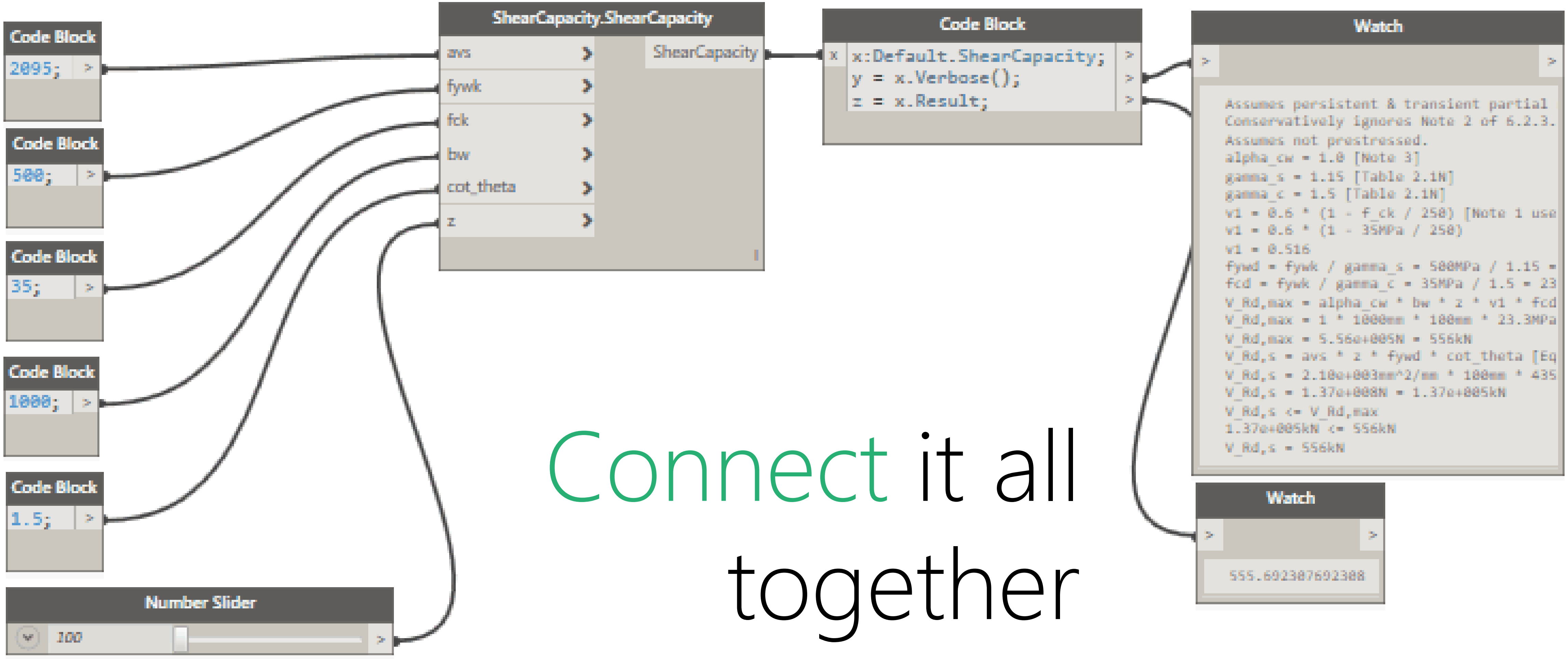
ARUP

"Hello!"

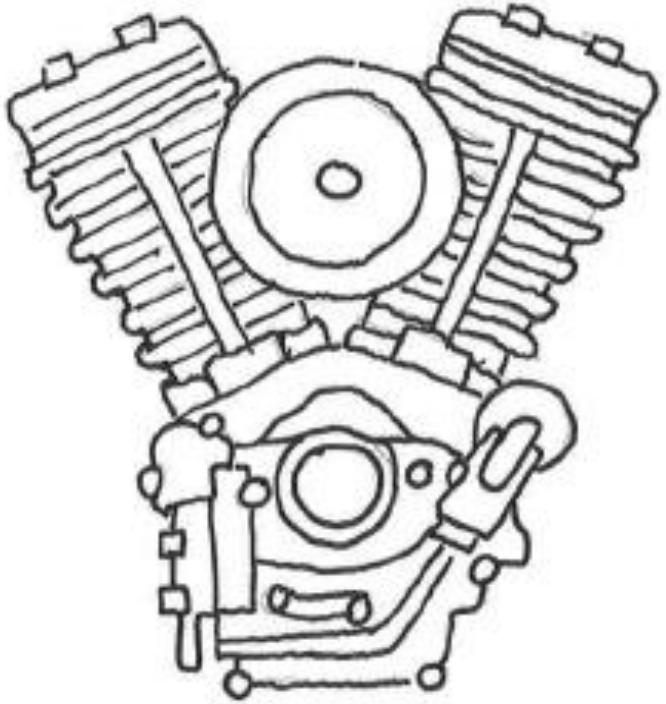
"I've got a calculation problem"

"We've got a data problem"

"Ah-ha!"

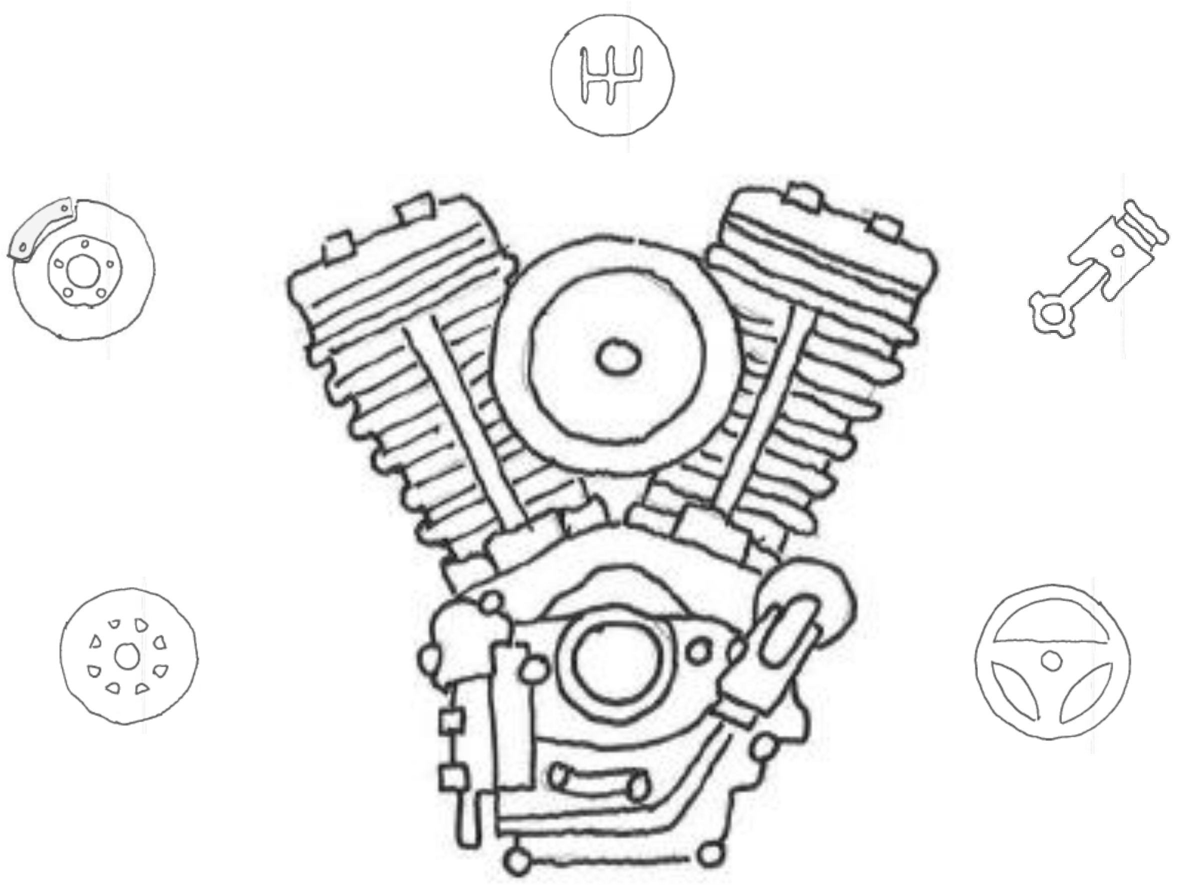


Connect it all together



We built an engine

ARUP



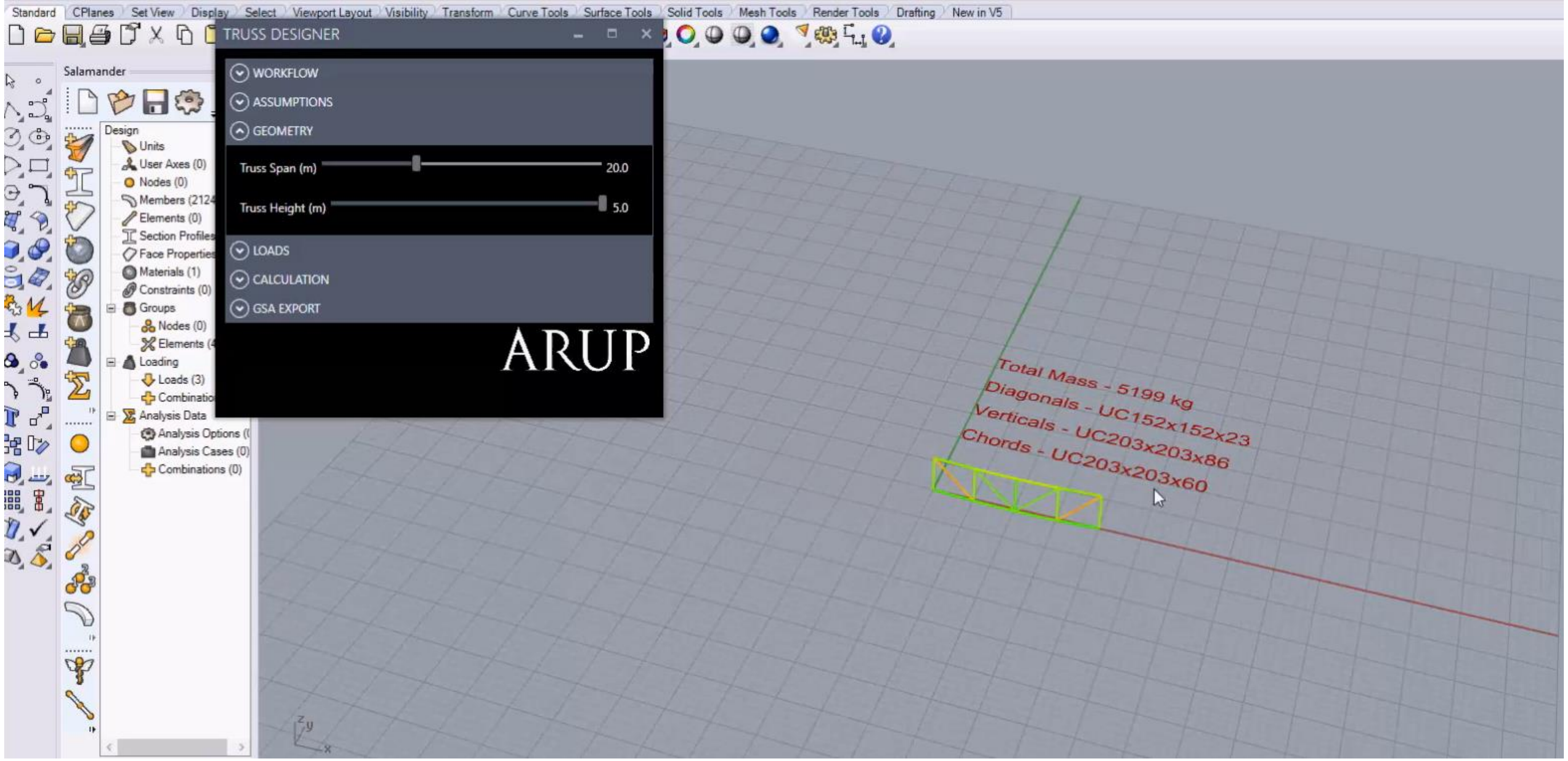
That could be
built around

ARUP

Lets be disruptive

So we tried it…

ARUP



My first parametric truss

ARUP

"Yeah, yeah – but what about the real stuff?"

- Everyone we work with.

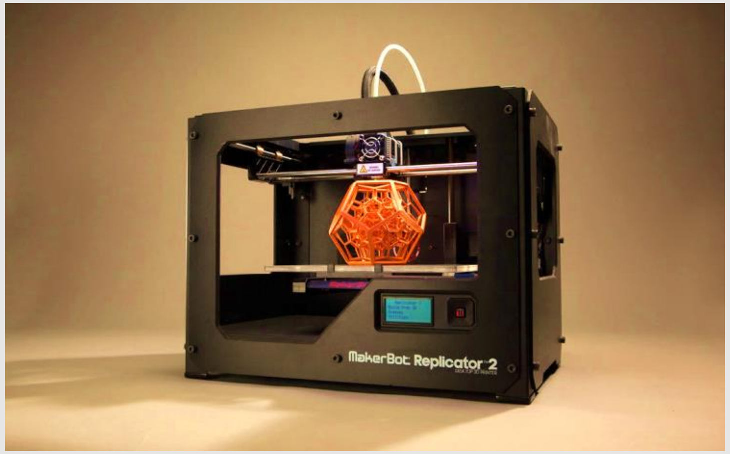
ARUP

Ok, ok, we'll take on something "real" then...

Leaving our comfort zone...

Hand crafted

Engineering the products one at a time



Mass bespoke

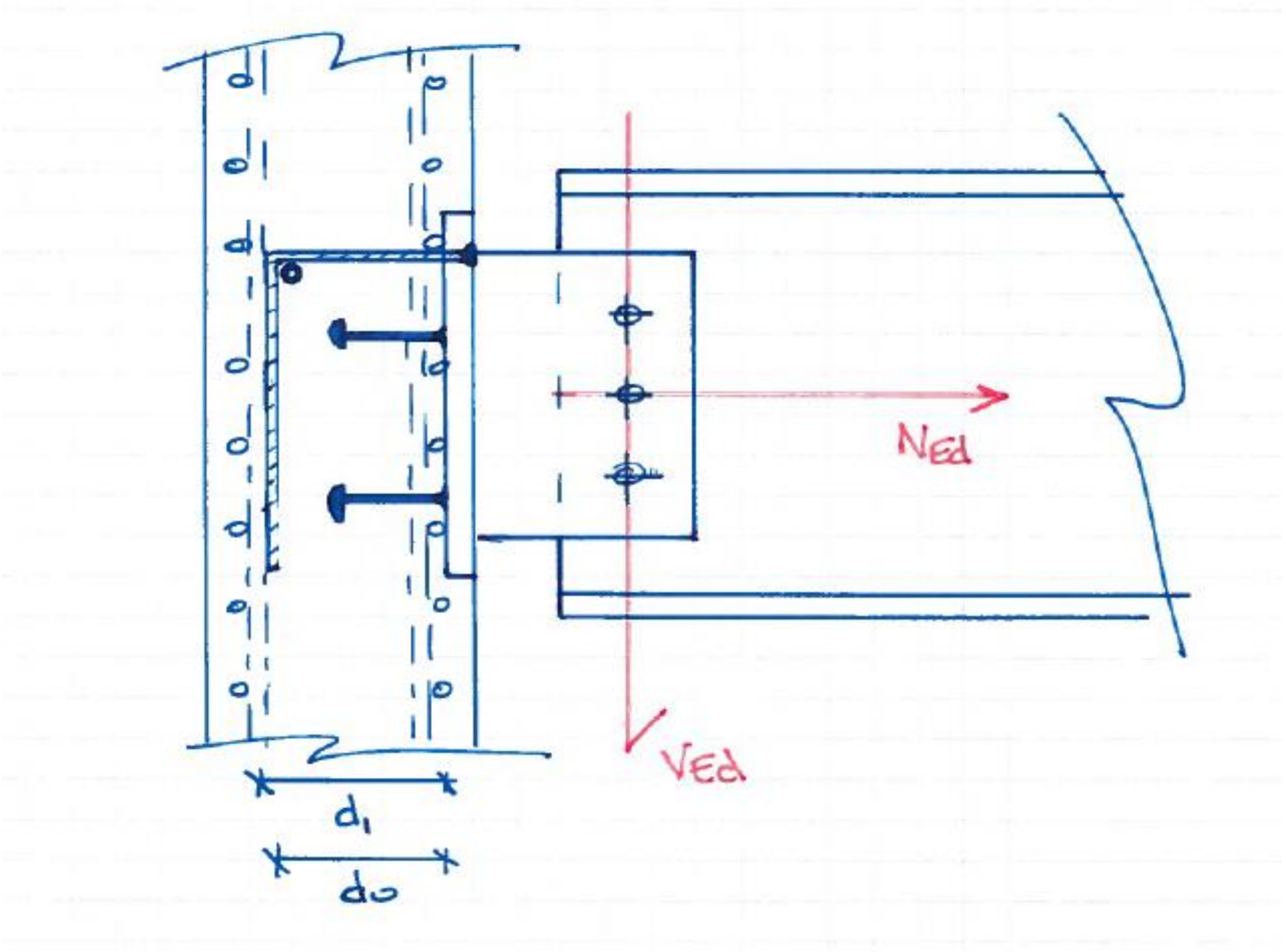
The model for how we need to be consistently working

Mass production

Engineering the process that creates the products

ARUP

Start with the hard problems



Why are they so complex?

ARUP

Standard design?

	A	B	C	D	E	F	G
20	***Design Checks***						
21							
22	***Rebar Anchor Design***				***Cast-In Plate Thickness***		
23							
24	***Bending Steel***				x	87.5	mm
25					P	312.5	kN
26	Design Shear Force, V_{Ed}	100	kN		Minimum Plate Thickness	27.9	mm
27	Lever Arm, z	160	mm		Chosen Plate Thickness	35	mm
28	Tension = Compression =	312.5	kN				
29							
30	***Robustness***				***Shear Stud Design***		
31							
32	Tie Force, T_{Ed}	50	kN		h_{sc}/d	5	
33	Axial Tension, T_A	0	kN		α	1	
34	$F_{Robustness}$	50	kN		$P_{Rd,1}$	81.7	kN
35					$P_{Rd,2}$	104.3	kN
36	***Anchor Design***				Design Stud Resistance, P_{Rd}	81.7	kN
37					$V_{Ed,z}$	100	kN
38	Max. Tensile Force	312.5	kN		No. Studs Required	1.22399	
39	Axial Tension Present?	No, top row of a					
40	$T_{max,top}$	312.5	kN				
41	$T_{max,bottom}$	0	kN				
42							
43	***Top Anchors***						
44							
45	No. of Top Anchors	2					

I	J	K	L
RC Wall			
Wall Depth, t_{wall}	300	mm	
Cover, c	40	mm	
Concrete Grade	C45/55		
Characteristic Cylinder Strength, f_{ck}	45	N/mm^2	
γ_c	1.5		
α_{cc}	0.85		
Design Compresive Strength, f_{cd}	25.5	N/mm^2	
$f_{ctk,0.05}$	2.7	N/mm^2	
E_{cm}	34400	N/mm^2	*Table 3.1 BS EN 1992-1-1-2004*
Horizontal Bar Diameter, Φ_h	20	mm	
Vertical Bar Diameter, Φ_v	12	mm	
Tension Bar Clearance	20	mm	
Transverse Bar at Tension Bend, Φ_{hb}	25	mm	

Local Effects

Punching Shear					
Q_{Ed}	6.75	kN	h_c		
h_c	110	mm	a_m	[illegible]	mm
h_f	20	mm	b_m	280	mm
c_p	1156.4	mm	b_{em}	2180	mm
bars	7	mm	m_{Ed}	2.94	kNm/m
spacing	200	mm	M_{Ed}	1.60	kNm
ρ_x	0.002539		m_{Ed}	5.73	kNm/m
ρ_y	0.002325		N_s	83.91	kN
ρ	0.00243		x_s	5.9	mm
V_{Rd}	0.31	N/mm^2	z_s	73	mm
V_{Rd}	28.29	kN	m_{Rd}	6.13	kNm/m

Connection ref:	B_1.0_048					
Beam Type	B14					
Min angle to wall >=90	81.77 °					

<u>**Local Forces**</u>

Tension	Compression	Vertical Shear	Horizontal Shear	Torsion	Moment Major	Tie Force
Fx	Fx	Fz	Fy	Mxx		Fz
Top & Bottom Rebar, Concrete	Top & Bottom Rebar, Concrete	Studs	Studs	Rebar / Concrete	Rebar / Concrete	Studs
480	0	250	0	0	0	0

Horizontal shear due to to beam not being perpendicular to wall

e1	185	mm
e2	185/tan81.77	
=	26.75779195	

Torsion moment due to eccentric vertical shear

Ved*e2

6.69 kNm

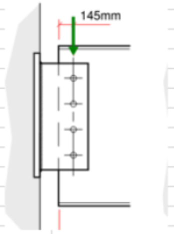
Additional horizontal shear due to the torsional moment

2*Ted/sv

Minimum vertical distance between centroids of shear stufs

sv	200.00	mm
H1	67	kN

Resolve local axial tension to global horizontal shear and global axial tension



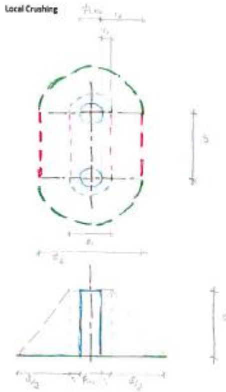
<u>Back Plate Design</u>

Checks: Local crushing of concrete
Punching Shear
Steel bending
Steel shear

Factors							
γM0	1						
γc	1.5						
α_{cc}	0.85						
fck	40	Mpa					
fcd	22.66667						
wall depth	250	mm					
c	30						
tcip	20				200	180	
tbp	20				ρly	ρlz	ρl
Φbending	20		ρ		0.010053096	0.011170107	0.02
rebar spacing	100						

Local crushing Check					
r1	20.00	mm	Ac0	61082.70793	mm2
			Ac1	165766.9718	mm2
ΦCHS	139.7	mm			
ACHS	109.72	mm2			
CHS c/L spacing, s	200	mm	Factor	2.713811772	<= 3
d	170	mm			
			Min Plate Dimensions for crushing (limited by		
			min Width	179.7	mm
Φ1	179.7	mm	min Length	379.7	mm
Φ2	349.7	mm			
			Max force on plate for crushing		
			F	1546.59404	kN

Local Crushing



No.

ARUP

"Lets change that!"

\- Us.

ARUP

We obtained funds…

…and built a team



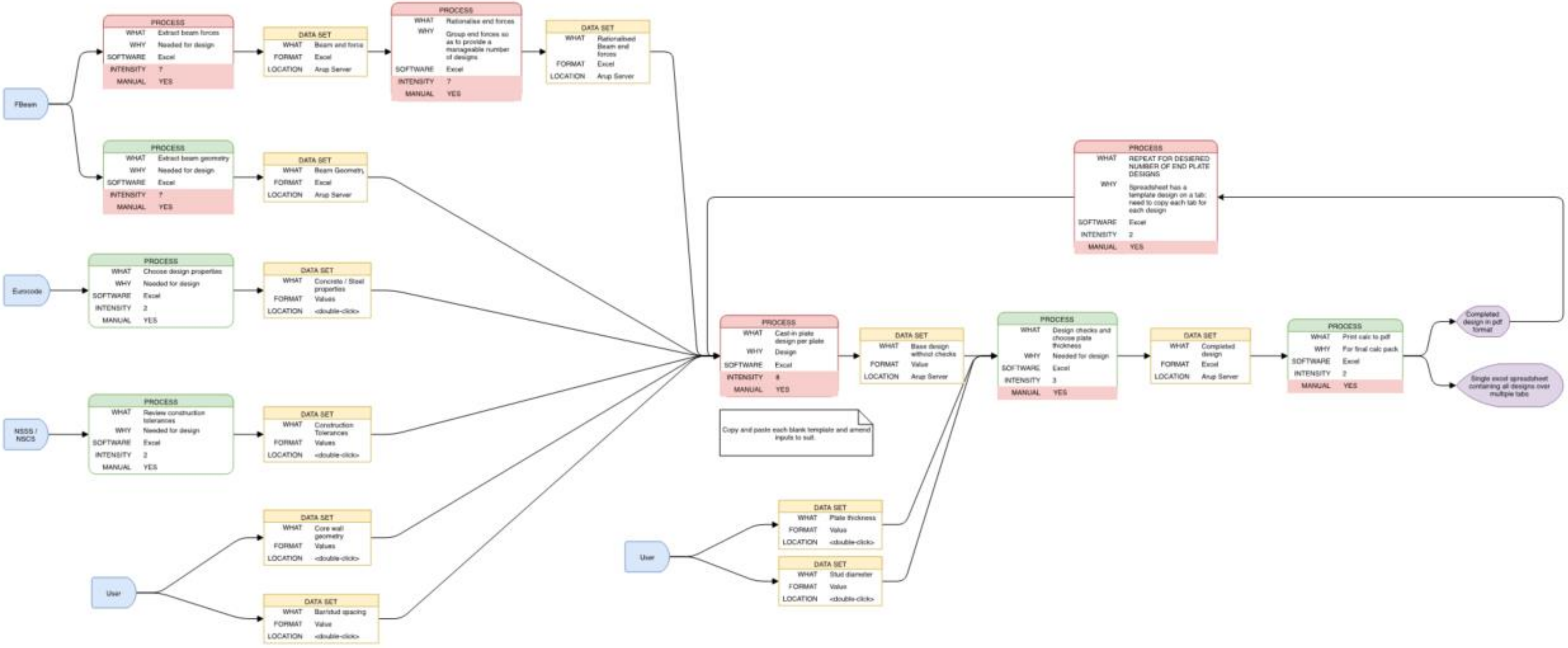
The Investors
A wealth of experience
And very open minds


The Innovators
Two people with a big idea
And a lot of coffee



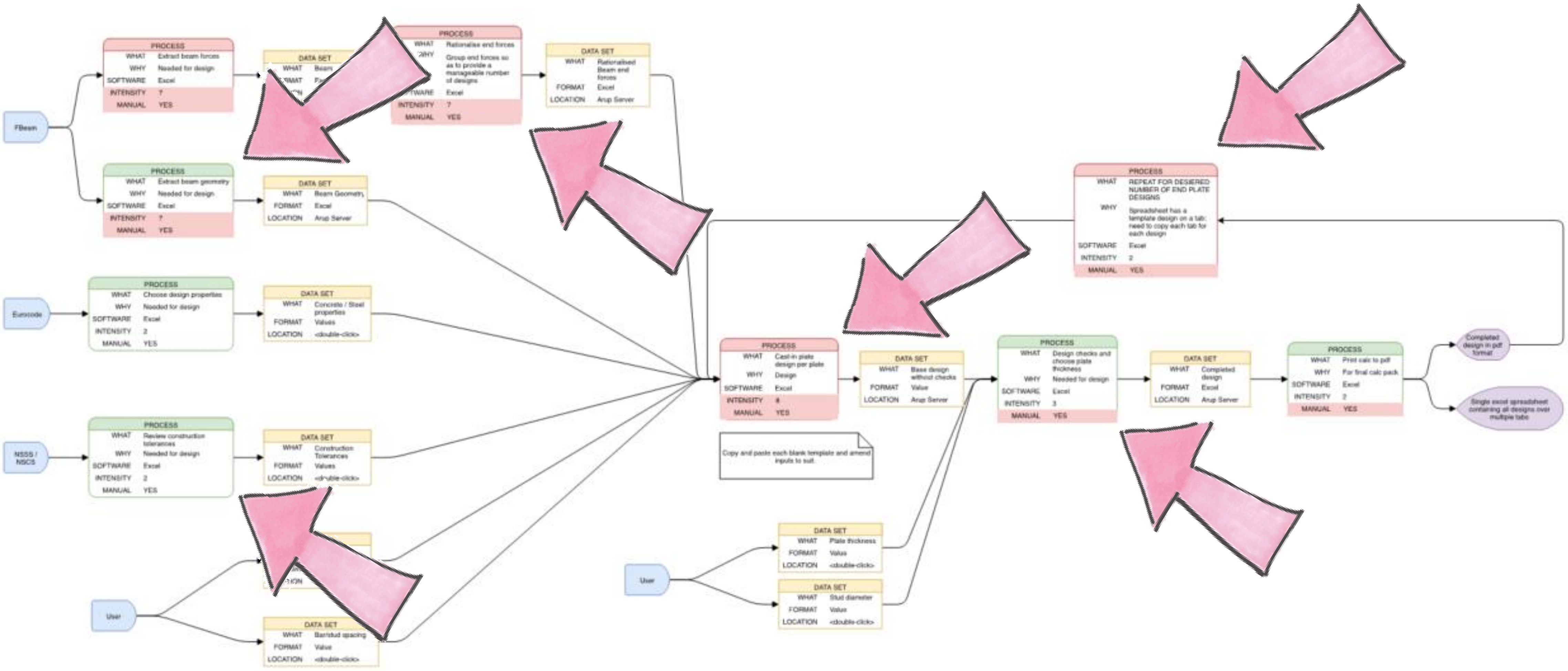
The Integrators
Digital natives
Impossible is not in their vocabulary

We mapped current methods…



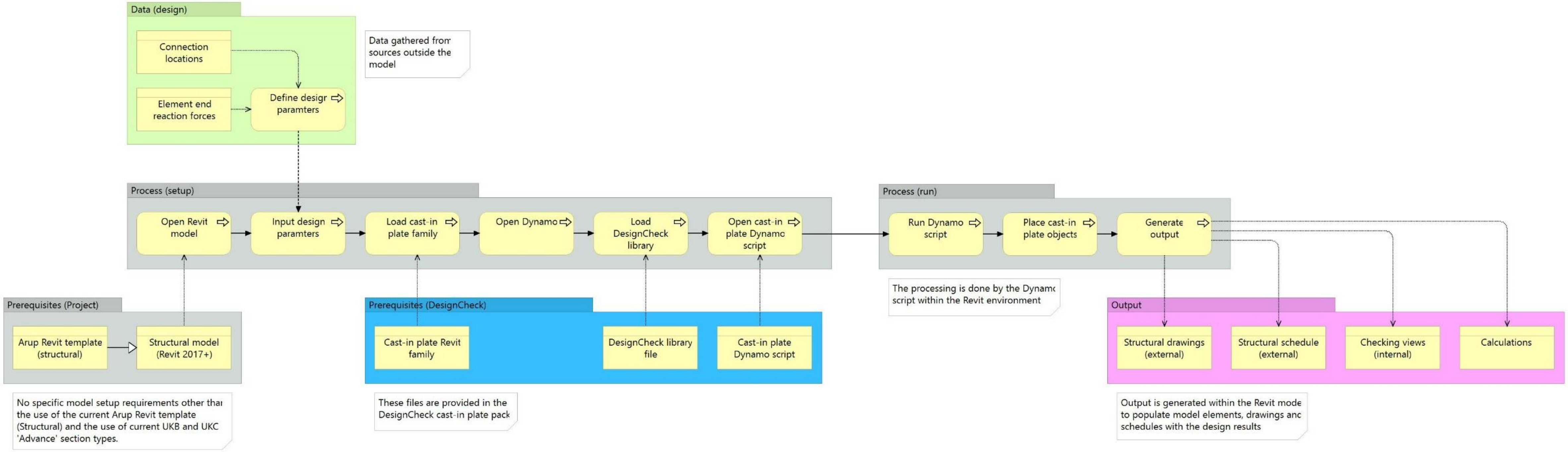
ARUP

..highlighted the pain points...



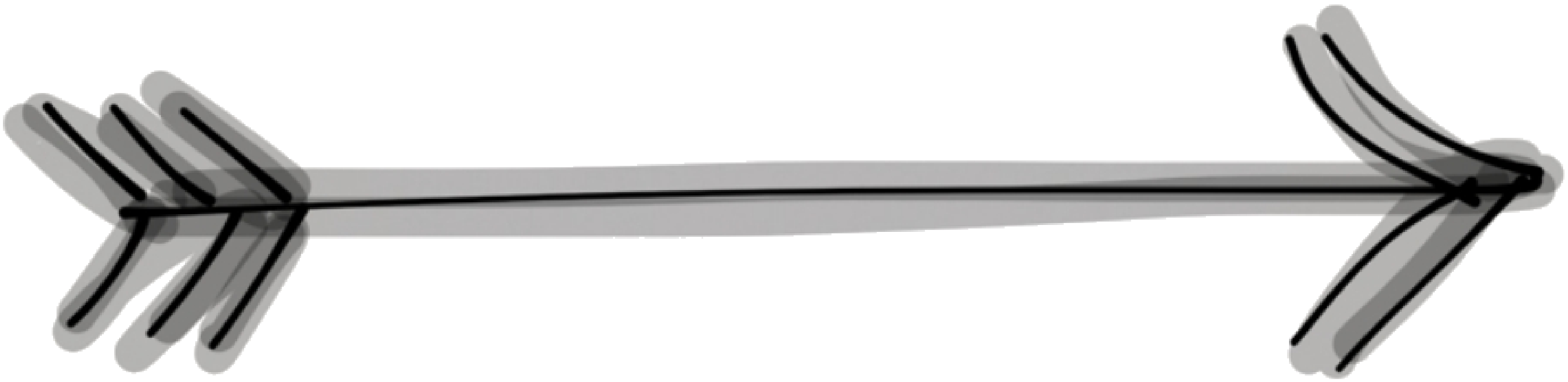
ARUP

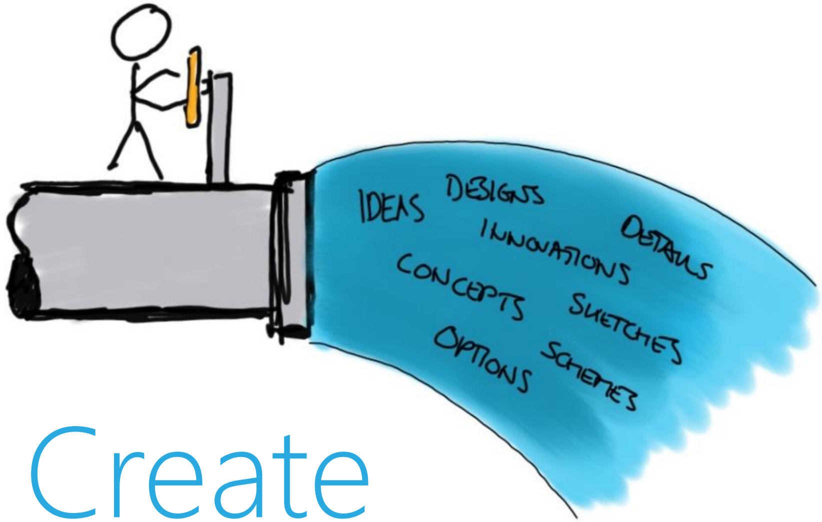
and made improvements...



ARUP

Creating flow

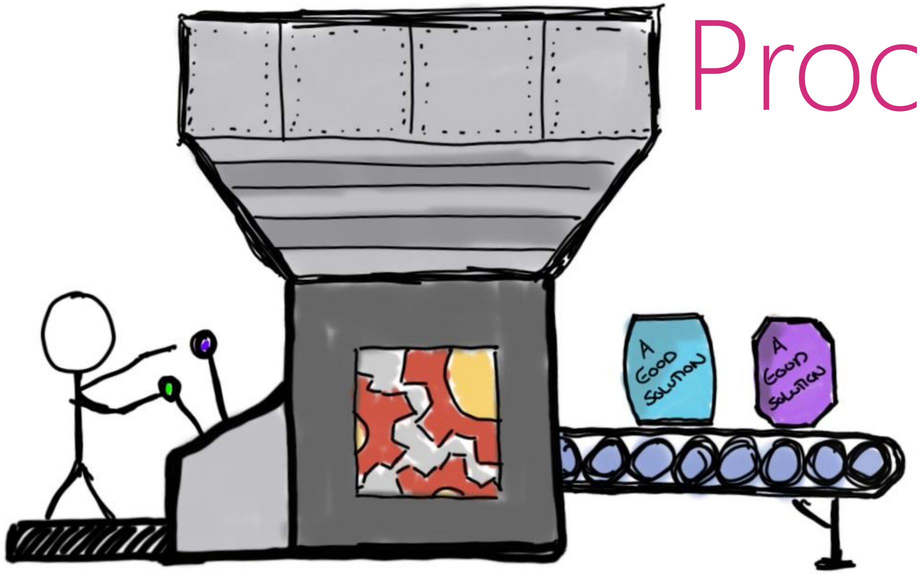




Create

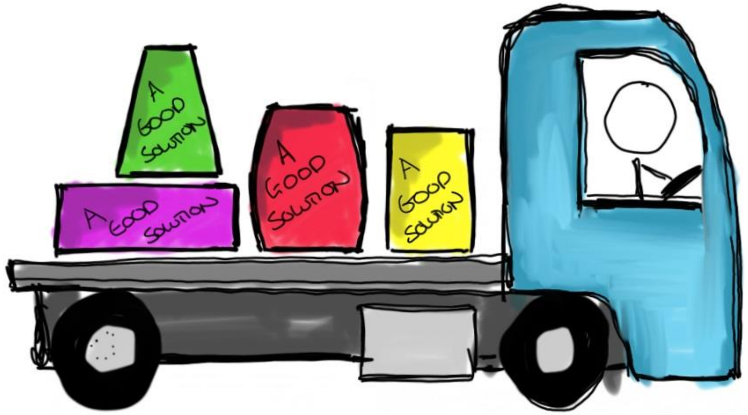
Follow the value

Eliminate the waste

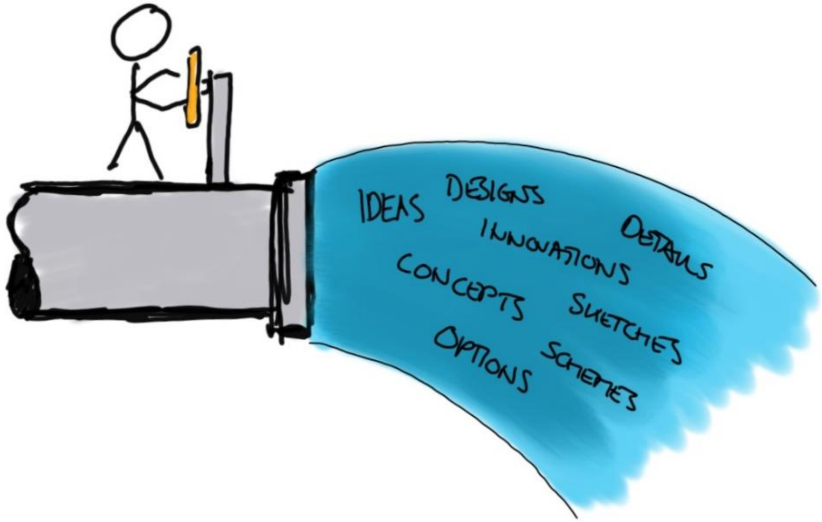


Process

Deliver

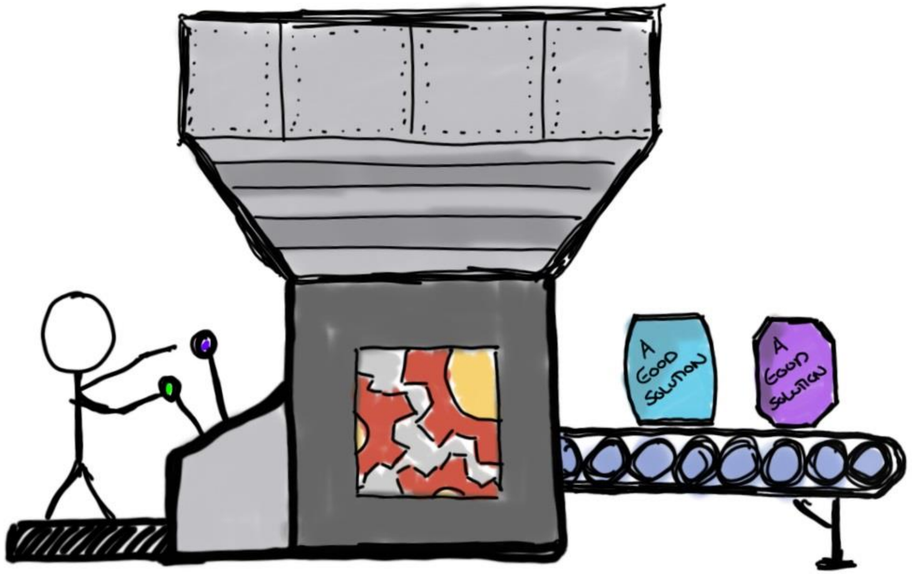


ARUP



Geometry
Data
Constraints
Targets

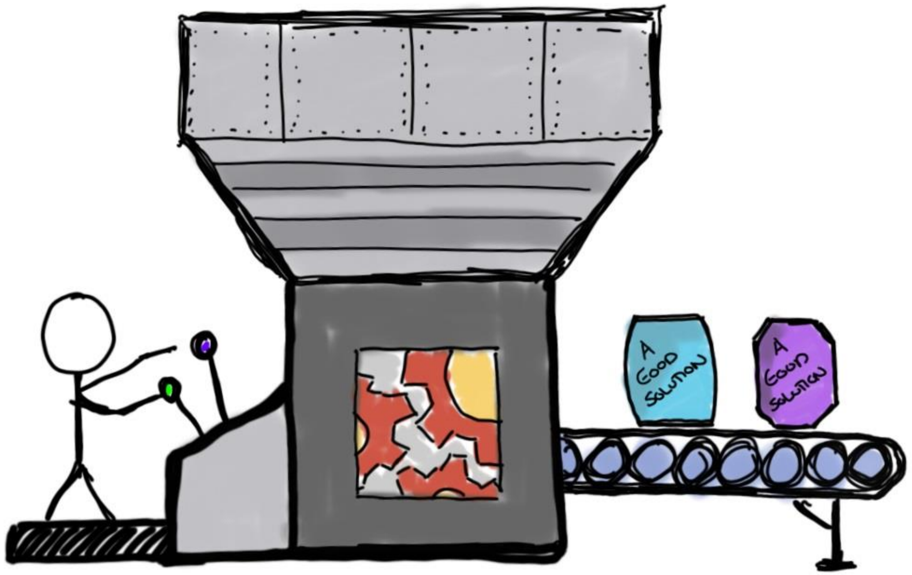
Input



ARUP

Output

Insights
Metrics
Information
Confirmation



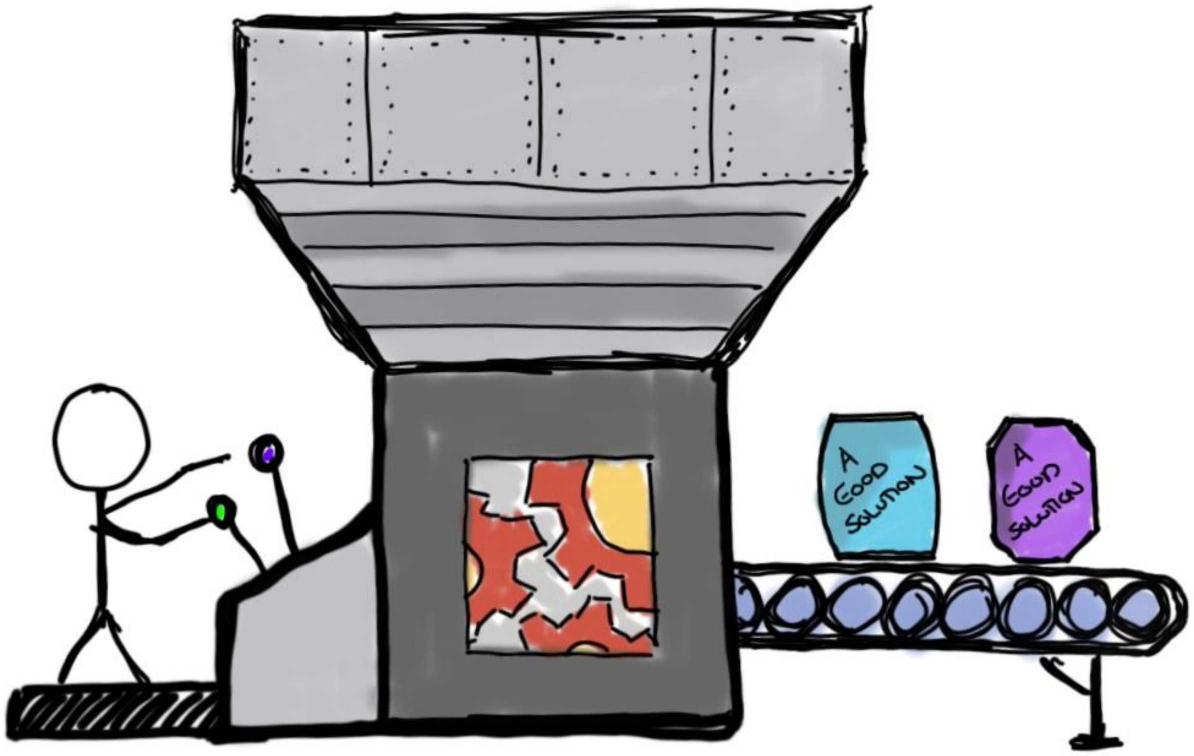
ARUP

We planned for a successful outcome

MUST	SHOULD
• Implement SGN 09 checks • Shear only • "Infinite" concrete • Two columns on studs / bars • Top x rows are bars • Revit object for plate • Fin plate centred on plate • Extensible for other codes ▪Alert the user when design assumptions aren't valid	• Alert the user if requirements for "infinite" concrete are not met (plus any other assumptions) • Resolve Axial load, moment, minor axis forces • X by Y arrangement of bars / studs • Variable number of top / bottom rows are bars • Revit object for plate + sub entities for bars, studs • Include basic clash checks for "thin" concrete (i.e. can the bent bars fit in) • Usage tracking
COULD	**(First Version) WON'T**
• Arbitrary substitution of studs for bars • ~~Moment~~ • Capacity reduction adjacent to edges / openings • Work for "thin" concrete i.e. plate through to other side of section • Other bar arrangements (hook-up, hook-side, studs only) • Use green book method for plate sizing • Template Revit checking views (governed by studs, governed by punching etc.)	• Design for hanger bars if there is an opening below • Web interface • Auto size • Non-fin plate connections

ARUP

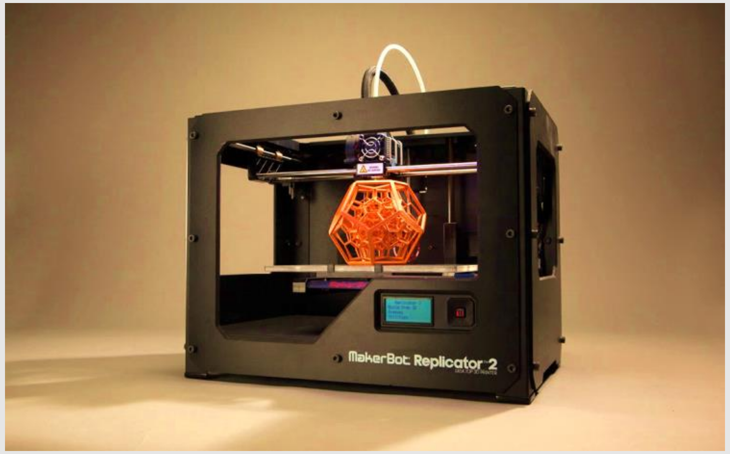
We developed our processing machine



Left our comfort zone...

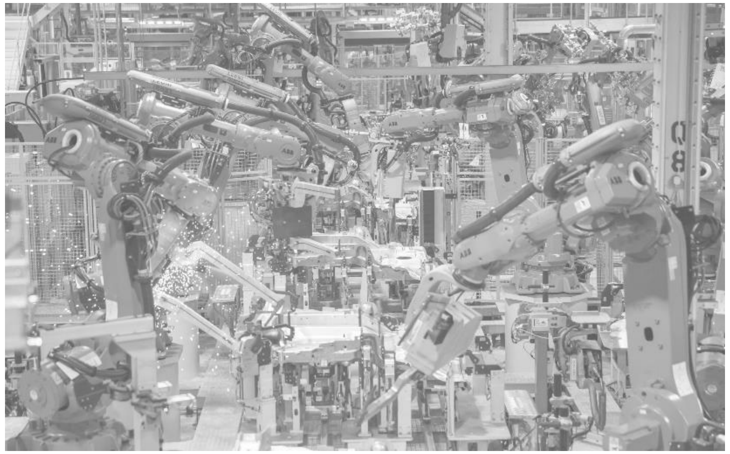
Hand crafted

Engineering the products one at a time



Mass bespoke

The model for how we need to be consistently working



Mass production

Engineering the process that creates the products

ARUP

STEP 1 RESISTANCES OF BOLT ROWS IN THE TENSION ZONE

RESISTANCES OF T-STUBS

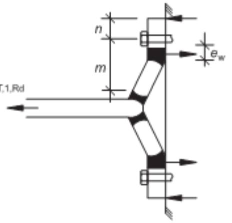
The resistances of the equivalent T-stubs are evaluated separately for the end plate and the column flange. The resistances are calculated for three possible modes of failure. The resistance is taken as the minimum of the values for the three modes.

The design resistance of the T-stub flange, for each of the modes, is given below.

Mode 1 Complete Flange Yielding

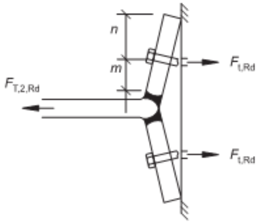
Using 'Method 2' in Table 6.2 of BS EN 1993-1-8:

$$F_{T,1,Rd} = \frac{(8n - 2e_w)M_{pl,1,Rd}}{2mn - e_w(m+n)}$$



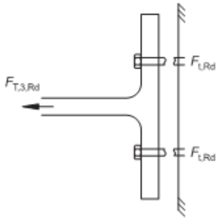
Mode 2 Bolt Failure with Flange Yielding

$$F_{T,2,Rd} = \frac{2M_{pl,2,Rd} + n(\Sigma F_{t,Rd})}{m+n}$$



Mode 3 Bolt Failure

$$F_{T,3,Rd} = \Sigma F_{t,Rd}$$



where:

$M_{pl,1,Rd}$ and $M_{pl,2,Rd}$ are the plastic resistance moments of the equivalent T-stubs for Modes 1 and 2, given by:

$$M_{pl,1,Rd} = 0.25 \Sigma \ell_{eff,1} t_f^2 f_y / \gamma_{M0}$$

$$M_{pl,2,Rd} = 0.25 \Sigma \ell_{eff,2} t_f^2 f_y / \gamma_{M0}$$

$\ell_{eff,1}$ is the effective length of the equivalent T-stub for Mode 1, taken as the lesser of $\ell_{eff,cp}$ and $\ell_{eff,nc}$ (see Table 2.2 for effective lengths for individual rows and Table 2.3 for groups of rows)

$\ell_{eff,2}$ is the effective length of the equivalent T-stub for Mode 2, taken as $\ell_{eff,nc}$ (see Table 2.2 for effective lengths for individual rows and Table 2.3 for groups of rows)

t_f is the thickness of the T-stub flange (= t_p or t_{fc})

f_y is the yield strength of the T-stub flange (i.e. of the column or end plate)

$\Sigma F_{t,Rd}$ is the total tension resistance for the bolts in the T-stub (= $2F_{t,Rd}$ for a single row)

e_w = d_w / 4

d_w is the diameter of the washer or the width across the points of the bolt head, as relevant

m is as defined in Figure 2.5

n is the minimum of:

e_c (edge distance of the column flange)

e_p (edge distance of the end plate)

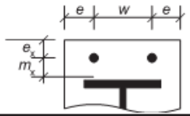
$1.25m$ (for end plate or column flange, as appropriate)

STEP 1A T-STUB FLANGE IN BENDING

Table 2.2 Effective lengths ℓ_{eff} for equivalent T-stubs for bolt row acting alone

(a) Pair of bolts in an unstiffened end plate extension

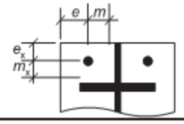
Note: Use m_x in place of m and e_x in place of n in the expressions for $F_{T,1,Rd}$ and $F_{T,2,Rd}$.



Circular patterns		Non-circular patterns	
	Circular yielding $\ell_{eff,cp} = 2\pi m_x$	yield lines	Double curvature $\ell_{eff,nc} = \frac{b_p}{2}$
	Individual end yielding $\ell_{eff,cp} = \pi m_x + 2e_x$		Individual end yielding $\ell_{eff,nc} = 4m_x + 1.25e_x$
	Circular group yielding $\ell_{eff,cp} = \pi m_x + w$		Corner yielding $\ell_{eff,nc} = 2m_x + 0.625e_x + e$
			Group end yielding $\ell_{eff,nc} = 2m_x + 0.625e_x + \frac{w}{2}$

(b) Pair of bolts at end of column or on a stiffened end plate extension

Note: The expressions below may also be used for a column without a stiffener except that the corner yielding pattern is not applicable.

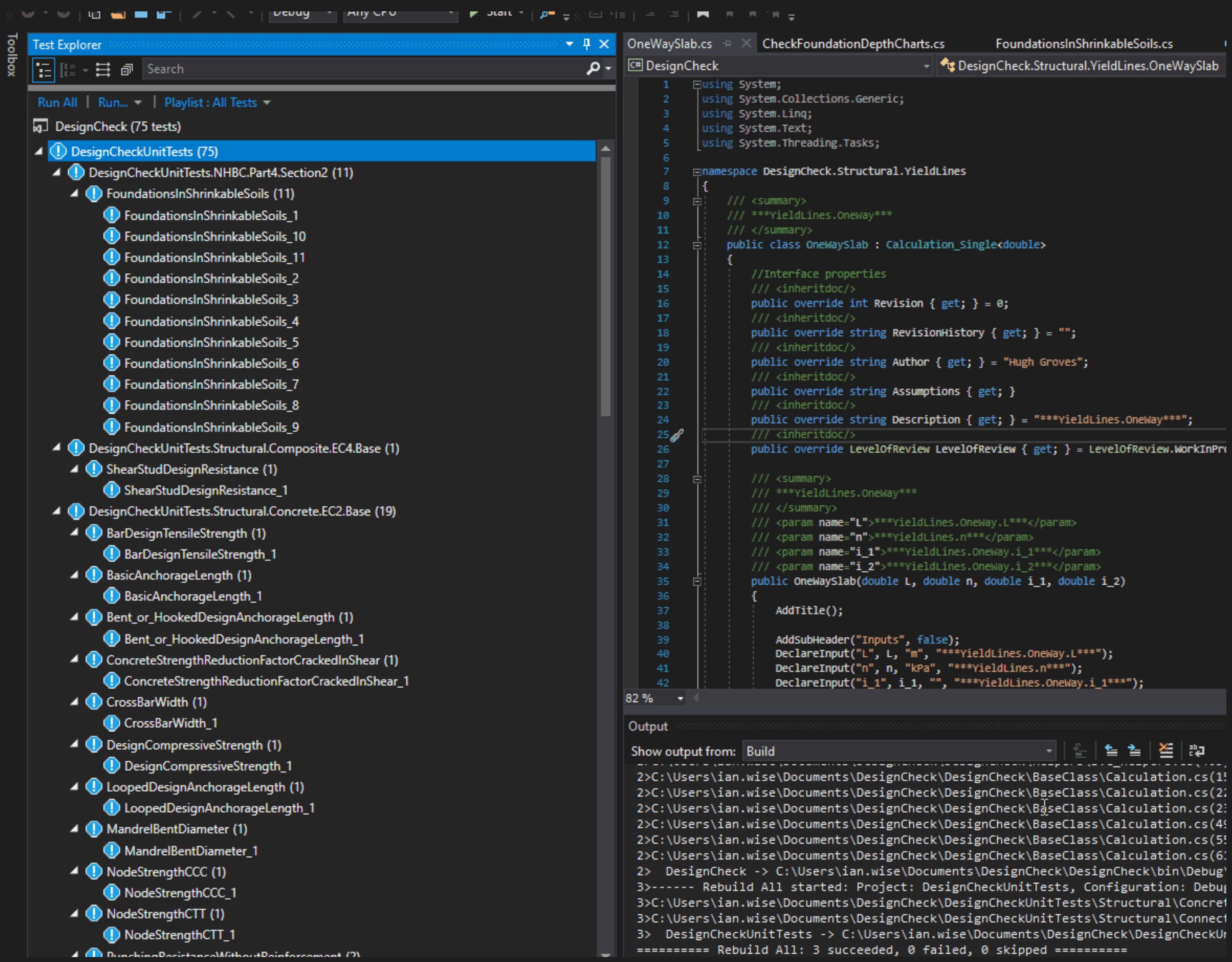


Circular patterns		Non-circular patterns	
	Circular yielding $\ell_{eff,cp} = 2\pi m$		Corner yielding $\ell_{eff,nc} = \alpha m - (2m + 0.625e) + e_x$
	Individual end yielding, $\ell_{eff,cp} = \pi m + 2e_x$		Corner yielding away from the stiffener/flange (m_x large) $\ell_{eff,nc} = 2m + 0.625e + e_x$

See Notes on Page 14

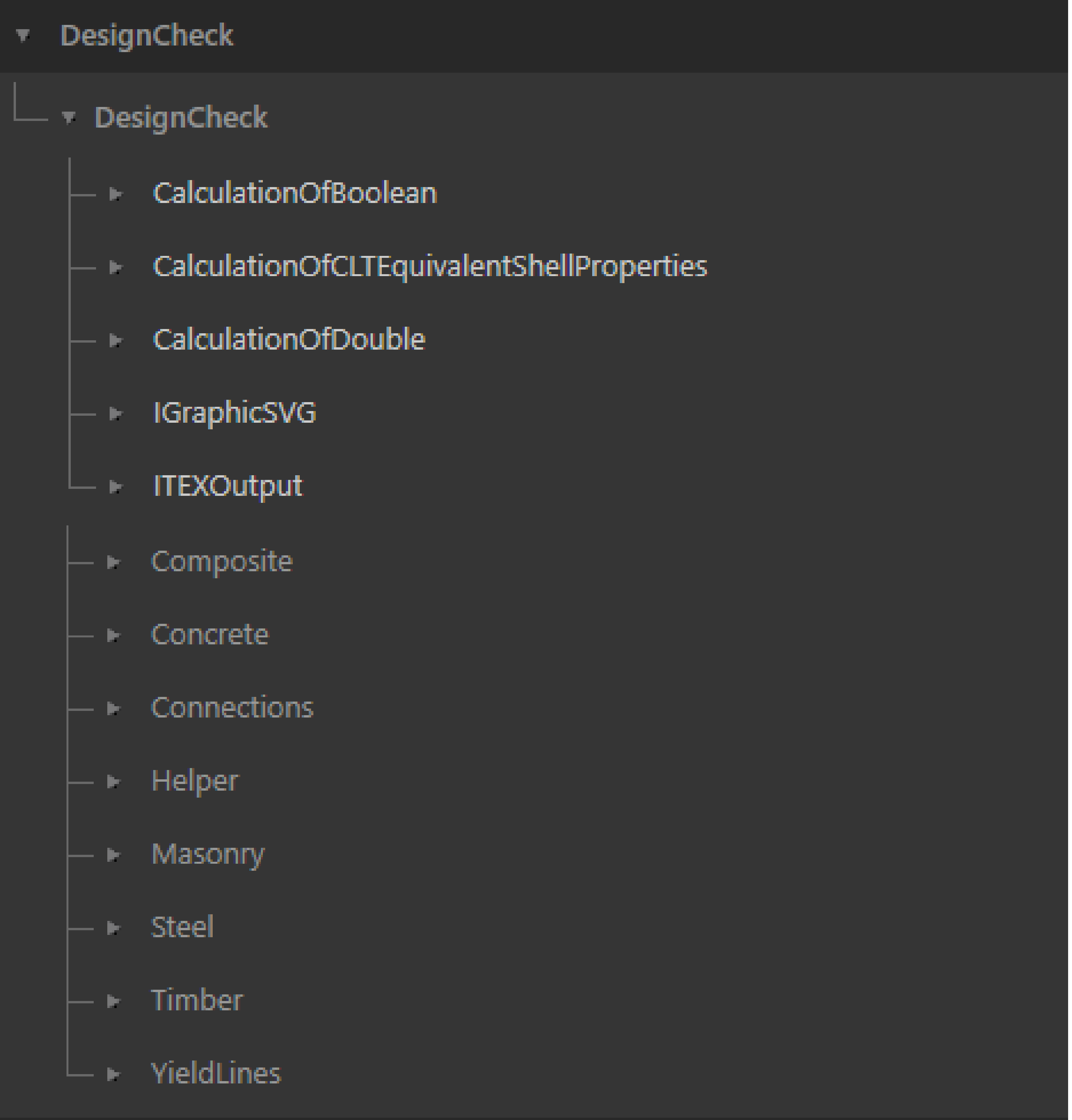
Reviewed guidance

ARUP



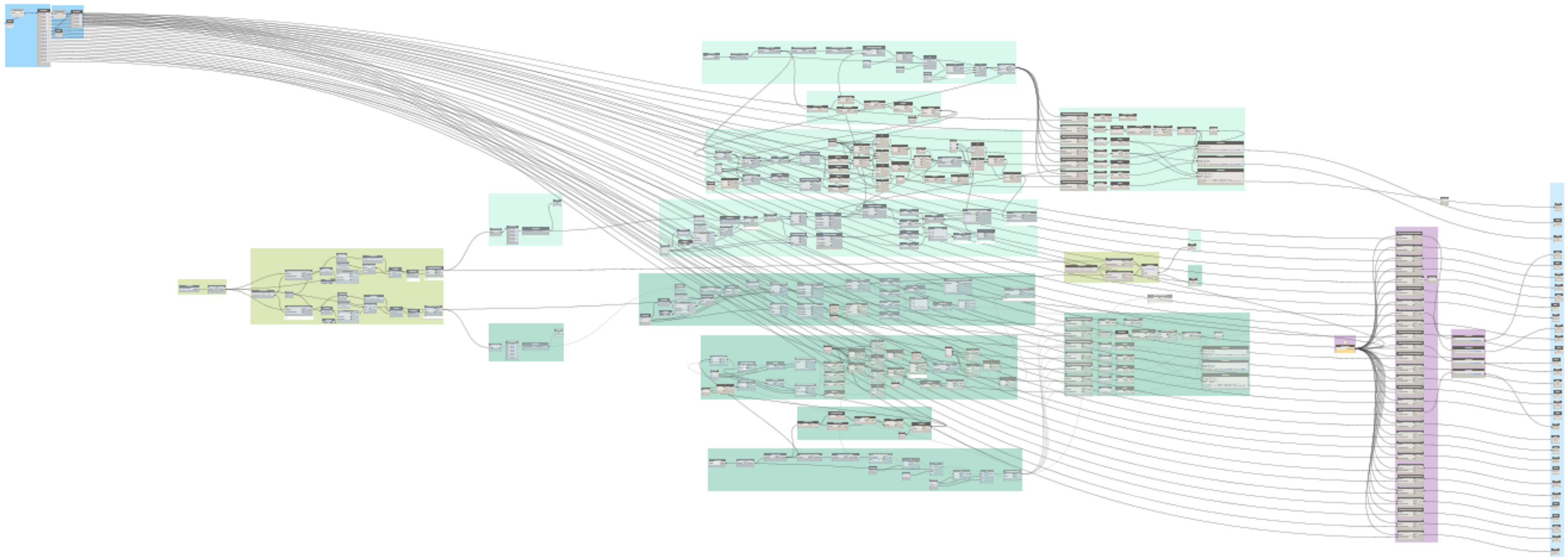
Coded the calculations

ARUP



Compiled the calculation library

ARUP

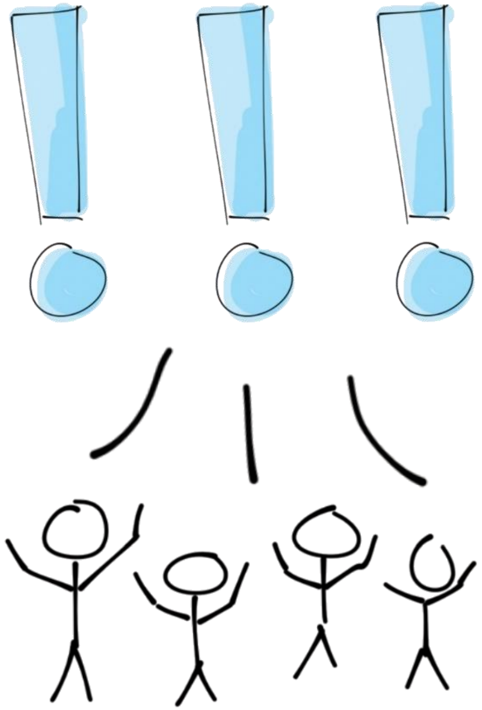


Parametric spaghetti

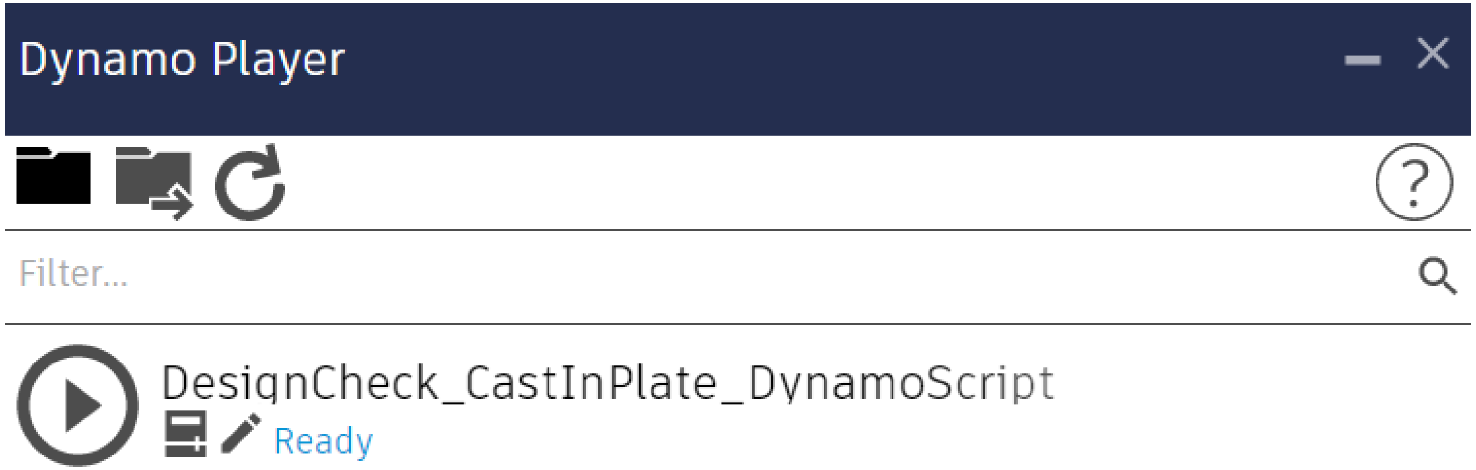
ARUP

```python
class Element:

    def __init__(self, id):
        self.id = id

    def get_id(sellf):
        return self.id

class Beam(Element):

    def __init__(self, id):
        super().__init__()


class Shell(Element):

    def __init__(self, id):
        super().__init__()

beam = Beam(1)

beam.get_id()

shell.get_id()
```

Removed external libraries…



ARUP



For simple mass roll-out

ARUP

Revit parameters used to drive the process:

Name	Type	Usage	*Notes*
Connection_End 1_Type	String	Tag with "CiP" to activate Dynamo	*Standard template parameter*
Connection_End 2_ Type	String	Tag with "CiP" to activate Dynamo	*Standard template parameter*
Connec tion_End 1_Shear_Vz Major	Number	Vertical shear input to Dynamo	*Standard template parameter*
Connection_End 2_Shear_Vz Major	Number	Vertical shear input to Dynamo	*Standard template parameter*
Reinforcement_Bars_Diameter_FF1	Number	Wall rebar input to Dynamo	*Standard template parameter*
Reinforcement_Bars_Diameter_FF2	Number	Wall rebar input to Dynamo	*Standard template parameter*
Reinforcement_Bars_Spacing_FF1	Number	Wall rebar input to Dynamo	*Standard template parameter*
Reinforcement_Bars_Spacing_FF2	Number	Wall rebar input to Dynamo	*Standard template parameter*
Reinforcement_Cover_Far Face	Number	Wall rebar input to Dynamo	*Standard template parameter*
Specification_Material_Strength Grade	Number	Wall concrete strength to Dynamo	*Standard template parameter*

Create the digital object

ARUP

Document everything

(*especially* the bits that **don't** work)

Bearing of plate on concrete

The general model has been to consider a cast in plate similarly to a base plate. With a typical column base plate a moment is resolved into a concentrated push-pull in the flanges of the column section. However, a fin plate is likely to induce a more even distribution of stress. This aspect has been reviewed by Ian Feltham from AT&R, who has suggested treating the concrete behind the cast in plate much like a typical reinforced concrete section. This has not been implemented due to time & budget constraints.

"*I would follow your alternative treatment, considering the concrete behind the cast-in plate similarly to how you would consider a normal reinforced concrete section. Providing the limiting strain (usually 0.0035) can be met, the rectangular stress block, starting at a distance from the neutral axis, results in a force and moment very similar to those from a realistic stress-strain relation; only if there were brittle components in the system (for example, some form of brittle shear stud) would this be inappropriate.* " - Ian Feltham 07/2017

Bottom node of strut and tie diagram

There is limited guidance on how to dimension the CCC node at the base of the cast in plate. Under guidance from Ian Feltham, for this project the height of the node has been taken equal to the depth of the compression block and the width has been taken as the minimum of the compression block width, or the stud spacing + z (i.e. assuming a 30-degree spread of stress).

Following these recommendations has led to the CCC node failing at very low loads. The design of this CCC node will require additional review.

Shear stud interaction

SGN 09 does not provide guidance on how shear studs interact, and so there are no limitations on closely spaced shear studs beyond trying to adhere to good practice. More guidance would be welcomed to allow a tool to inform a user of poor spacings.

Stress block relative to fin plate

Current guidance does not relate compression block position to the fin plate, but to the bottom edge of the plate. In extreme cases where the plate extends a long way from the bottom of the fin plate the plate would clearly be too flexible for this diagram to form. Additional guidance is required.

Strut and tie diagram / additional links

Current practice is generally to avoid introducing additional links behind the cast in plate, however the guidance suggests that for cot(theta) > 1.5 links are required to form a modified strut and tie diagram. Current guidance suggests that the bearing stress block grows from the base of the cast in plate, leading to high strut angles and thus requiring links behind the plate.

As deep plates are often required to allow more shear studs to be introduced an alternative could be that the strut initially forms at a desirable / low energy angle, with the plate forming a compression block that grows from nearer the middle of the plate. Only for higher loads on a given plate arrangement would the modified strut and tie diagram be required. Clearly this approach would result in higher forces in the anchorage bars than for a deeper 'z', and so the engineer would need to choose between having larger anchorage bars or introducing additional links.

Further research would be required to guide a logical approach to the strut & tie diagram and stress block locations.

Axial force in wall

Impact of axial force in the wall is not addressed in guidance.

ARUP

Last modified at 20/02/2018 12:07 PM by Hugh Groves [Edit this page]

DesignCheck - Cast In Plates

Page Rating
★★★★★ 3

Categories
No categories were selected

Background

The DesignCheck framework is a vision of the digital future of structural engineering. The aim is to create an ecosystem of design tools for 'stand-alone' structural components that combines detailed and verified engineering calculations with simple user interaction through a variety of software platforms.

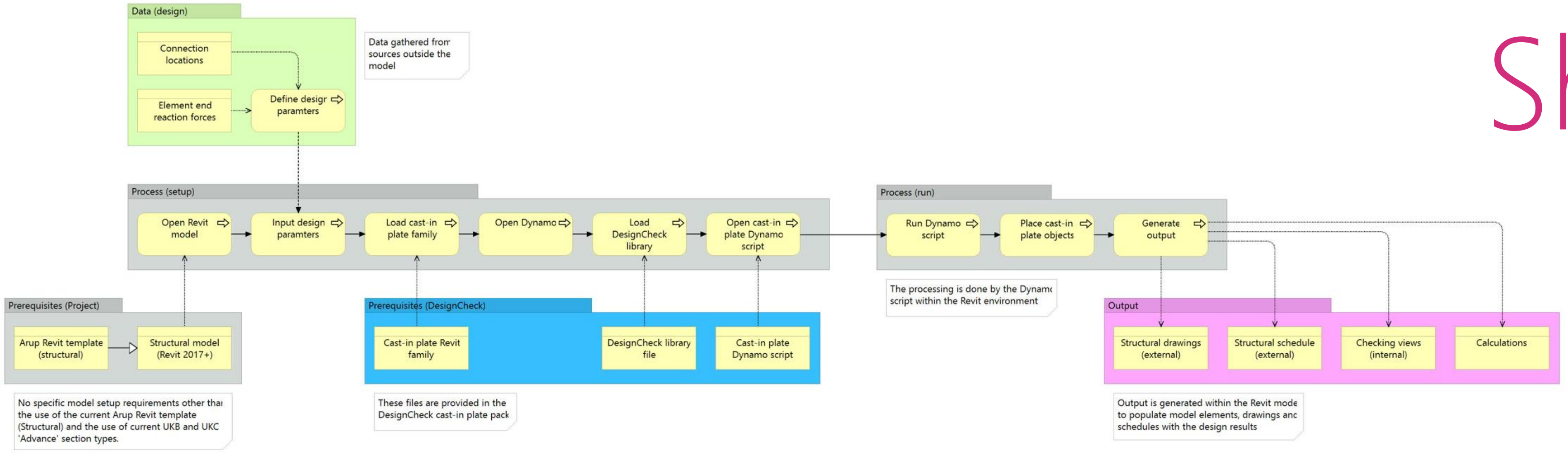
The fundamental basis is the creation of a centralised repository of code based design checking calculations that plug into a local users automated workflow. This could be Grasshopper and Dynamo based, or through more direct pure coding approaches. The work documented here represents the first step in building this framework using the practical example of cast-in plate connections through Dynamo in a structural Revit model.

IiA 17006: http://invest.intranet.arup.com/?lay out=projsheet&pro jid =17006&tab=projsheetdetailstabpage0

DesignCheck community site: https://arup.sharepoint.com/sites/community-digital-design/designcheck

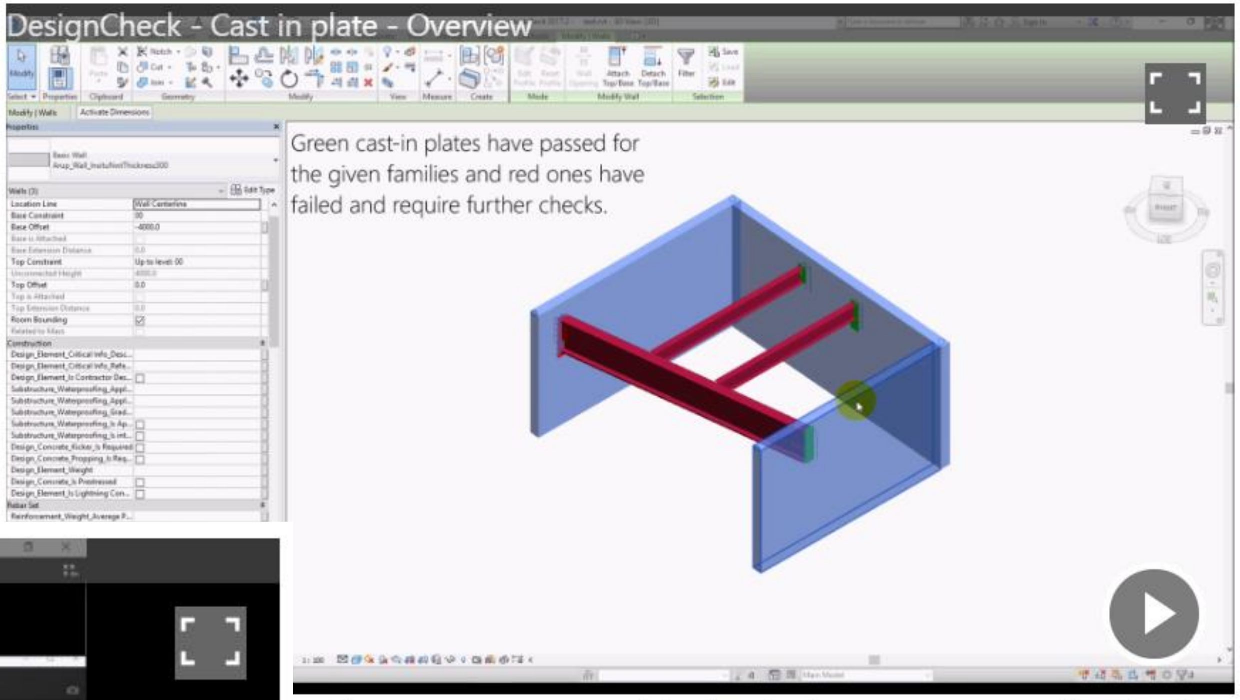
Process

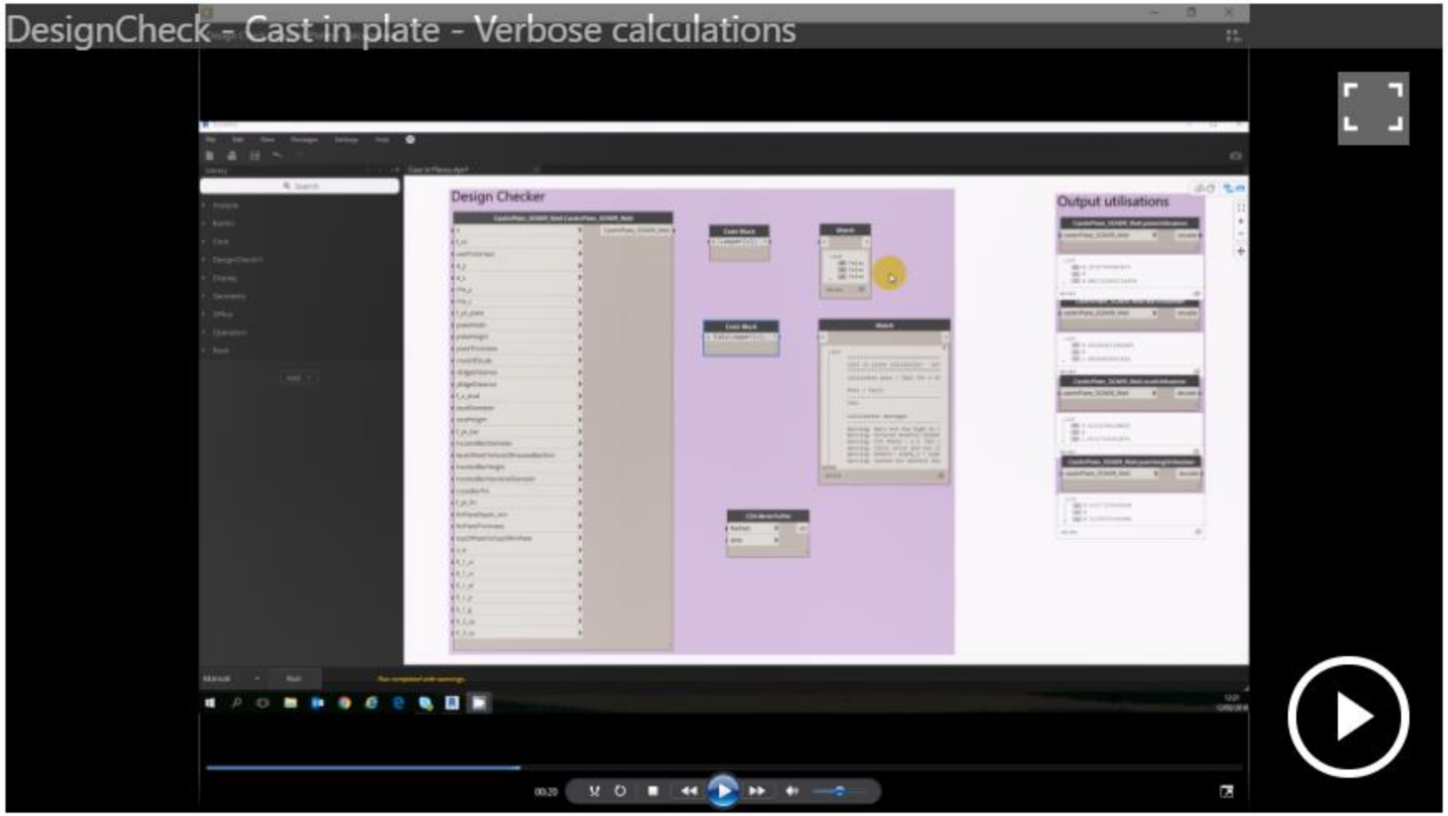
This tool has been developed around a defined workflow that is inherent in the operation of the tool. The archimate process map below (and downloadable further down this page) documents the steps required for successful execution of the tool and indicates the required inputs and outputs.



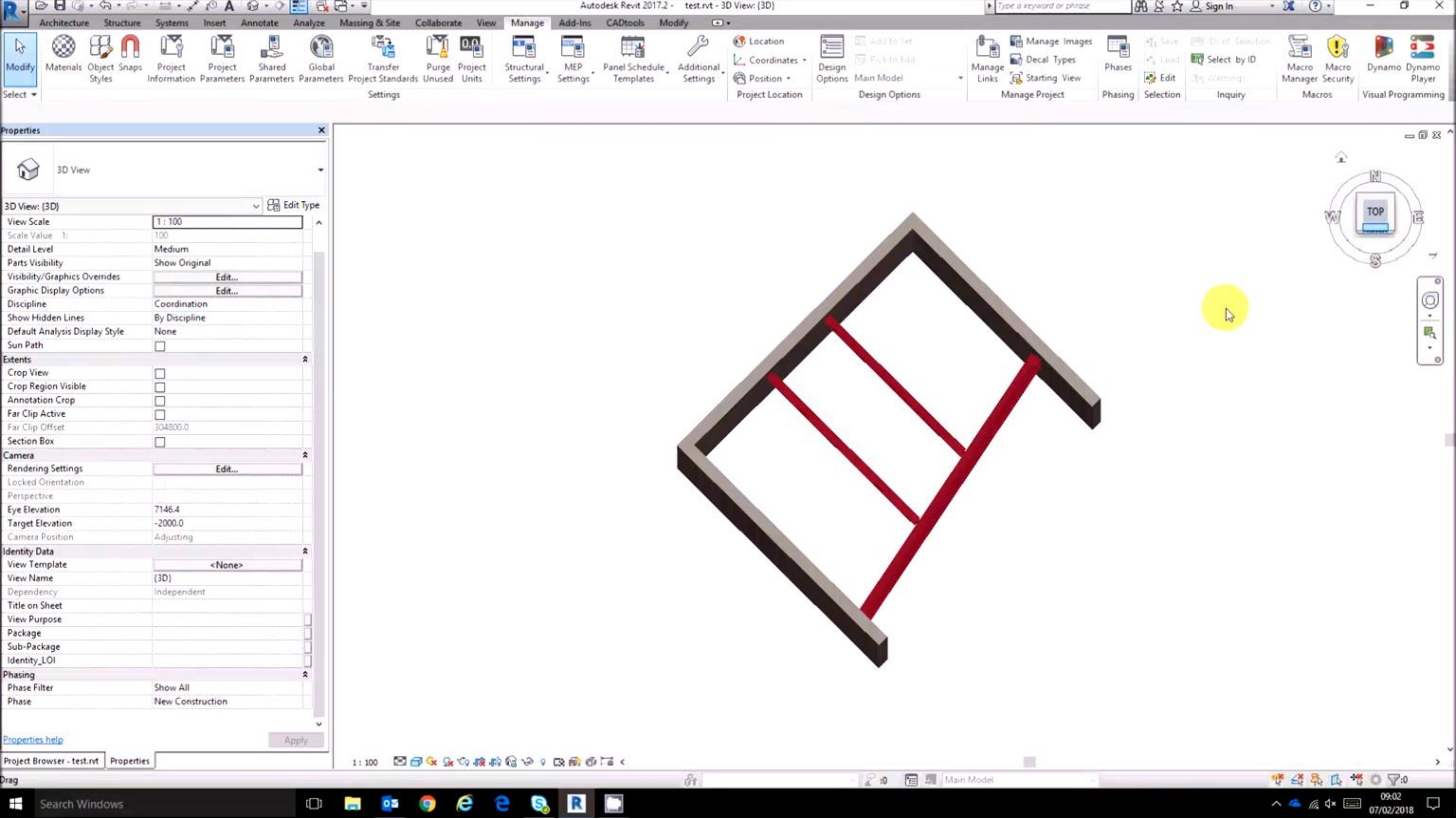
Share it

Showcase it





ARUP


Autodesk Revit 2017.2 - test.rvt - 3D View: {3D}
Type a keyword or phrase
Sign In
Architecture
Structure
Systems
Insert
Annotate
Analyze
Massing & Site
Collaborate
View
Manage
Add-Ins
CADtools
Modify
Modify
Materials
Object Styles
Snaps
Project Information
Project Parameters
Shared Parameters
Global Parameters
Transfer Project Standards
Purge Unused
Project Units
Structural Settings
MEP Settings
Panel Schedule Templates
Additional Settings
Location
Coordinates
Position
Design Options
Main Model
Manage Links
Manage Images
Decal Types
Starting View
Phases
Edit
Select by ID
Macro Manager
Macro Security
Dynamo
Dynamo Player
Select
Settings
Project Location
Design Options
Manage Project
Phasing
Selection
Inquiry
Macros
Visual Programming
Properties
3D View
3D View: {3D}
Edit Type
View Scale
1 : 100
Scale Value 1:
100
Detail Level
Medium
Parts Visibility
Show Original
Visibility/Graphics Overrides
Edit...
Graphic Display Options
Edit...
Discipline
Coordination
Show Hidden Lines
By Discipline
Default Analysis Display Style
None
Sun Path
Extents
Crop View
Crop Region Visible
Annotation Crop
Far Clip Active
Far Clip Offset
304800.0
Section Box
Camera
Rendering Settings
Edit...
Locked Orientation
Perspective
Eye Elevation
7146.4
Target Elevation
-2000.0
Camera Position
Adjusting
Identity Data
View Template
<None>
View Name
{3D}
Dependency
Independent
Title on Sheet
View Purpose
Package
Sub-Package
Identity_LOI
Phasing
Phase Filter
Show All
Phase
New Construction
Properties help
Apply
Project Browser - test.rvt
Properties
TOP
N
W
E
S
1 : 100
Drag
Main Model
Search Windows
09:02
07/02/2018

0:00:10

ARUP

“What can we do with the model output?”

- Everyone we work with.

ARUP

Type Properties

Family: Cast in Plate - Type Family

Type: 2x5 Studs, 2xB16 Anchors

Load...

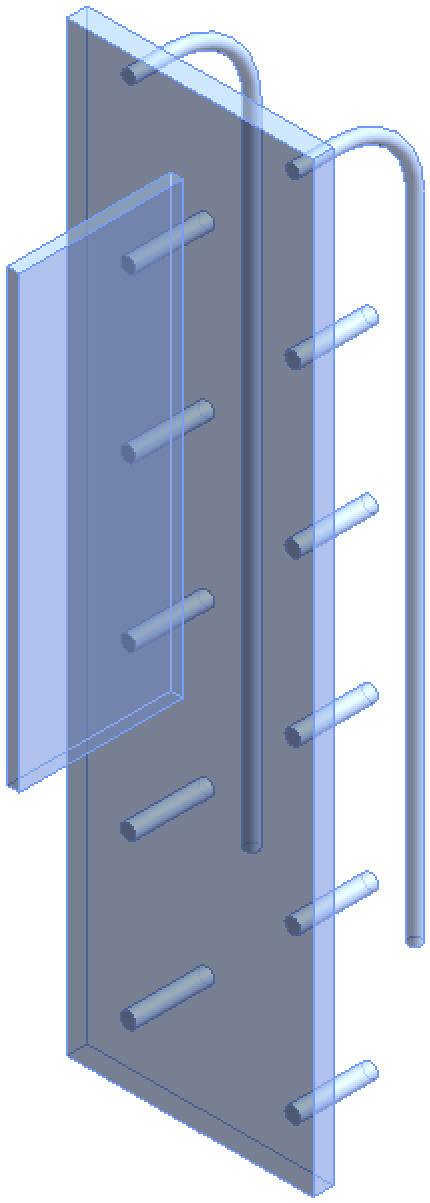
Duplicate...

Rename...

Type Parameters

Parameter	Value
Dimensions	
Cast In Plate Height	1100.0
Cast-In Plate Thickness	25.0
Cast-In Plate Width	300.0
Fin Plate Length	200.0
Fin Plate Offset From Centre of	23.0
Fin Plate Thickness	15.0
Minimum Fin Plate Depth	550.0
Rebar Anchor Diameter	16.0
Rebar Anchor Horizontal Length	150.0
Rebar Anchor Mandrel Diameter	96.0
Rebar Anchor Radius	8.0
Rebar Anchor Vertical Length	900.0
Shear Stud Diameter	19.0
Shear Stud Height	95.0
Shear Stud Y Spacing	200.0
Stud & Anchor X Edge Distance	50.0

<< Preview | OK | Cancel | Apply

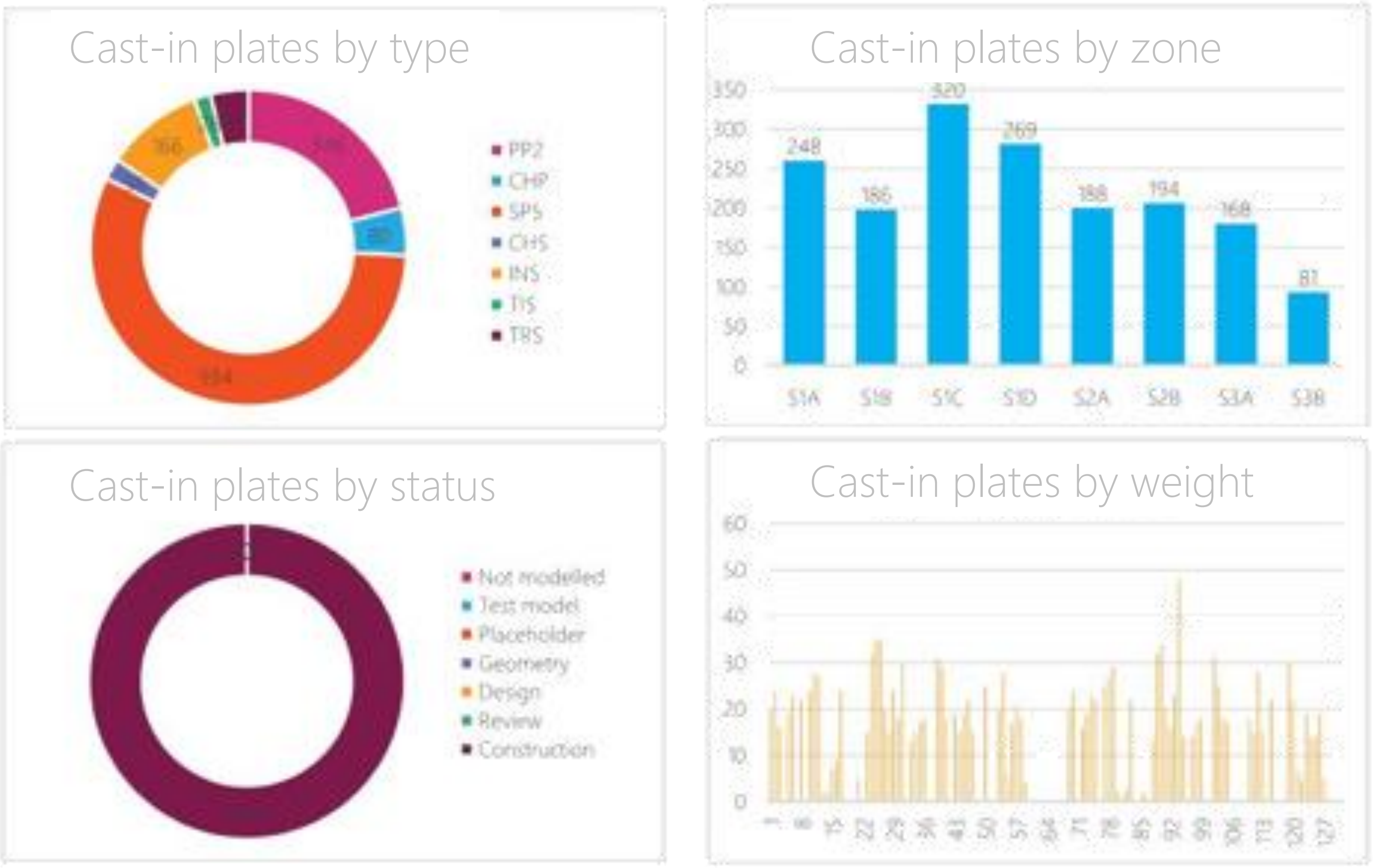


Review the model

ARUP

```
************************************************************
Cast in plate calculation - with reference to SGN09 & Eurocodes 2, 3, 4
************************************************************
Calculates pass / fail for a SGN_09 style cast in plate i.e. two 90 degree hook bars, two columns of studs, set in an 'infinite & uninterrupted' wall

Pass / fail?
------------------------------------------------------------
FAIL

Calculation messages
------------------------------------------------------------
Warning: Bars are too high in the plate. Taking account of vertical and horizontal tolerances of the fin plate the centroid of the bars must be at 45 degrees from the top of the fin plate. Plate strength calculations may not be valid. (CastInPlate_SGN09_Wall)
Warning: Entered mandrel diameter is less than minimum required by EC2 8.3(2) (CastInPlate_SGN09_Wall)
Warning: Cot theta > 1.5. Out of scope of calculation. Shear reinforcement likely required (CastInPlate_SGN09_Wall)
Warning: Fails strut and tie checks. Utilisation = 2.18998397530985 (CastInPlate_SGN09_Wall)
Warning: Remark: alpha_2 * alpha_3 * alpha_5 < 0.7, thus their product is now taken to be 0.7, clause (8.5) (StraightDesignAnchorageLength)
Warning: Hooked bar mandrel diameter is too small resulting in concrete crushing on the inside of the bend. Utilisation = 1.17 (CastInPlate_SGN09_Wall)
Warning: Plate thickness exceeds recommended geometry requirements to avoid secondary moments. (CastInPlate_SGN09_Wall)
Warning: Plate thickness exceeds recommended geometry requirements to avoid secondary moments. (CastInPlate_SGN09_Wall)
Remark: Plate weighs more than 20kg, consider manual handling (CastInPlate_SGN09_Wall)
Remark: Remark: alpha_2 * alpha_3 * alpha_5 < 0.7, thus their product is now taken to be 0.7, clause (8.5) (StraightDesignAnchorageLength)

Utilisations
------------------------------------------------------------
Plate utilisation: 0.294
Bar utilisation (yield): 0.461
Stud utilisation: 0.413
Strut utilisation: 0.331
CTT node utilisation: 0.265
CCC node utilisation: 2.19
Concrete crushing (inside of mandrel) utilisation: 1.17
Anchorage utilisation: 0.244
Punching shear utilisation: 0.113

Assumptions
------------------------------------------------------------
Assumes not influenced by adjacent cast in plates. Assumes not above an opening. Assumes not adjacent to an edge. Assumes design to UK National Annex. Assumes persistent & transient load factors.

Verbose calculation
------------------------------------------------------------
Identification of tolerances (SGN09 Step 1)
Calculation of eccentricity of applied shear to face of the plate
E_1 = E_1_ct + E_1_cc + E_1_p + E_1_sf + E_1_g
E_1 = 35mm + 45mm + 10mm + 0mm + 10mm
E_1 = 100mm
```

Review the output text



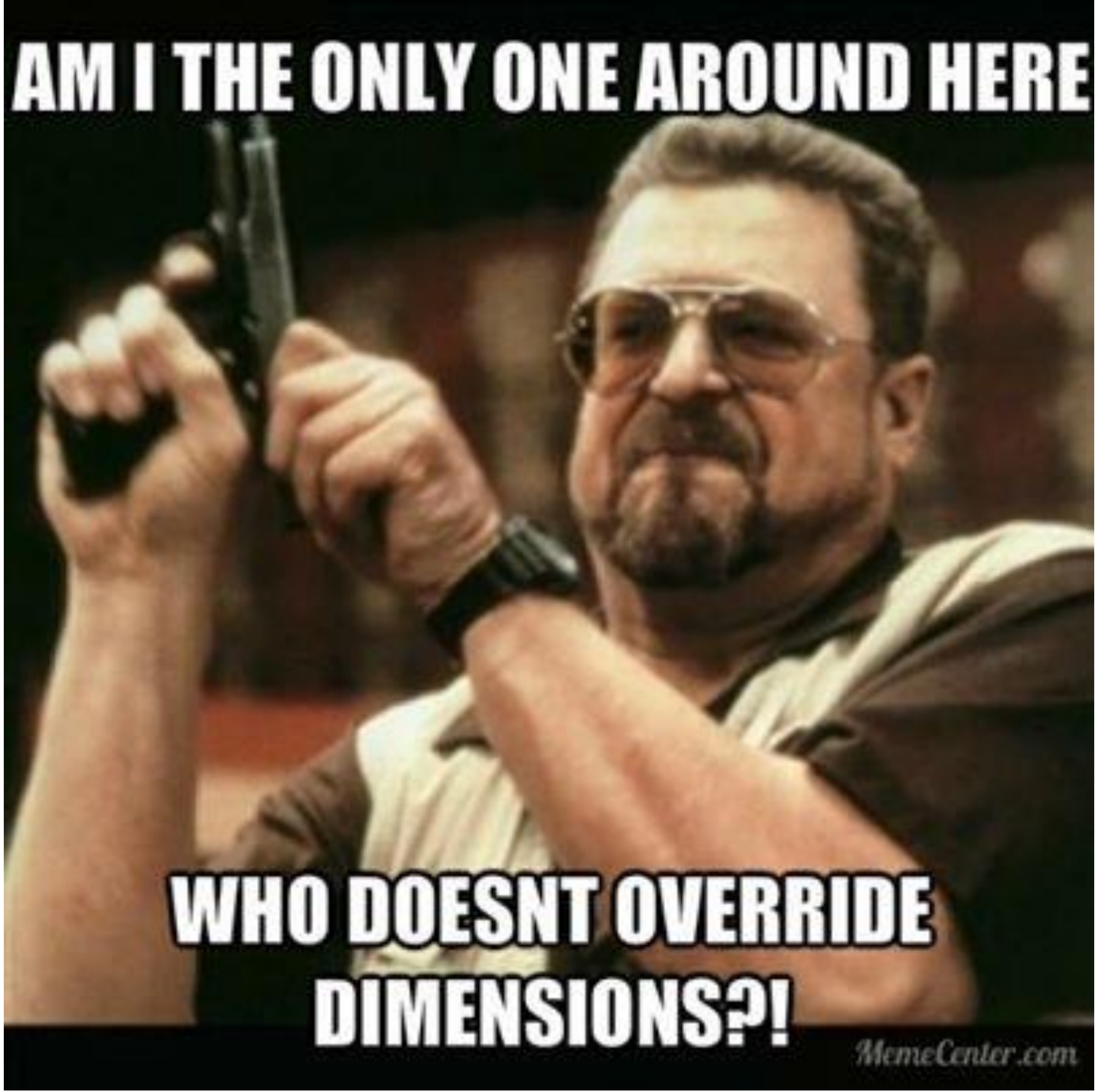
Review the metrics

ARUP

Digital production

Modelling for success

ARUP


AM I THE ONLY ONE AROUND HERE
WHO DOESNT OVERRIDE DIMENSIONS?!
MemeCenter.com

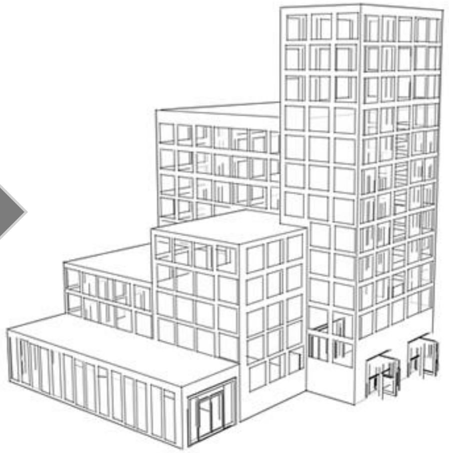
ARUP

A model first approach

ARUP

IN

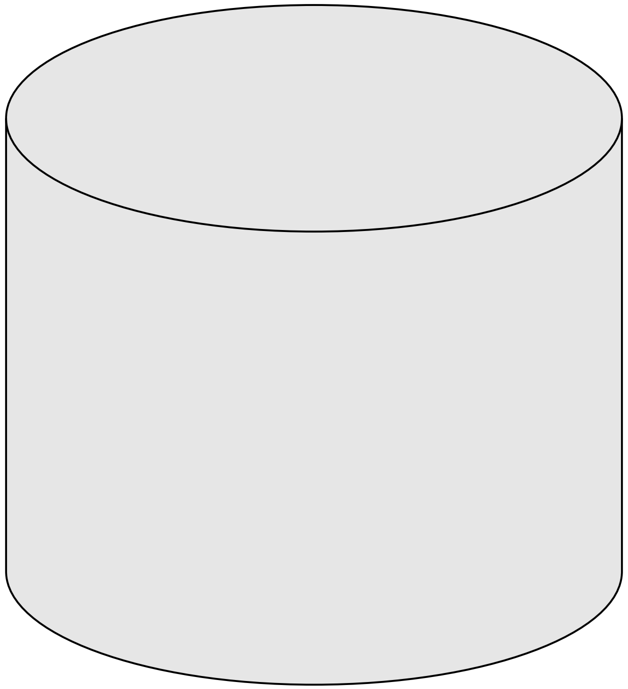
Everything



OUT

Everything

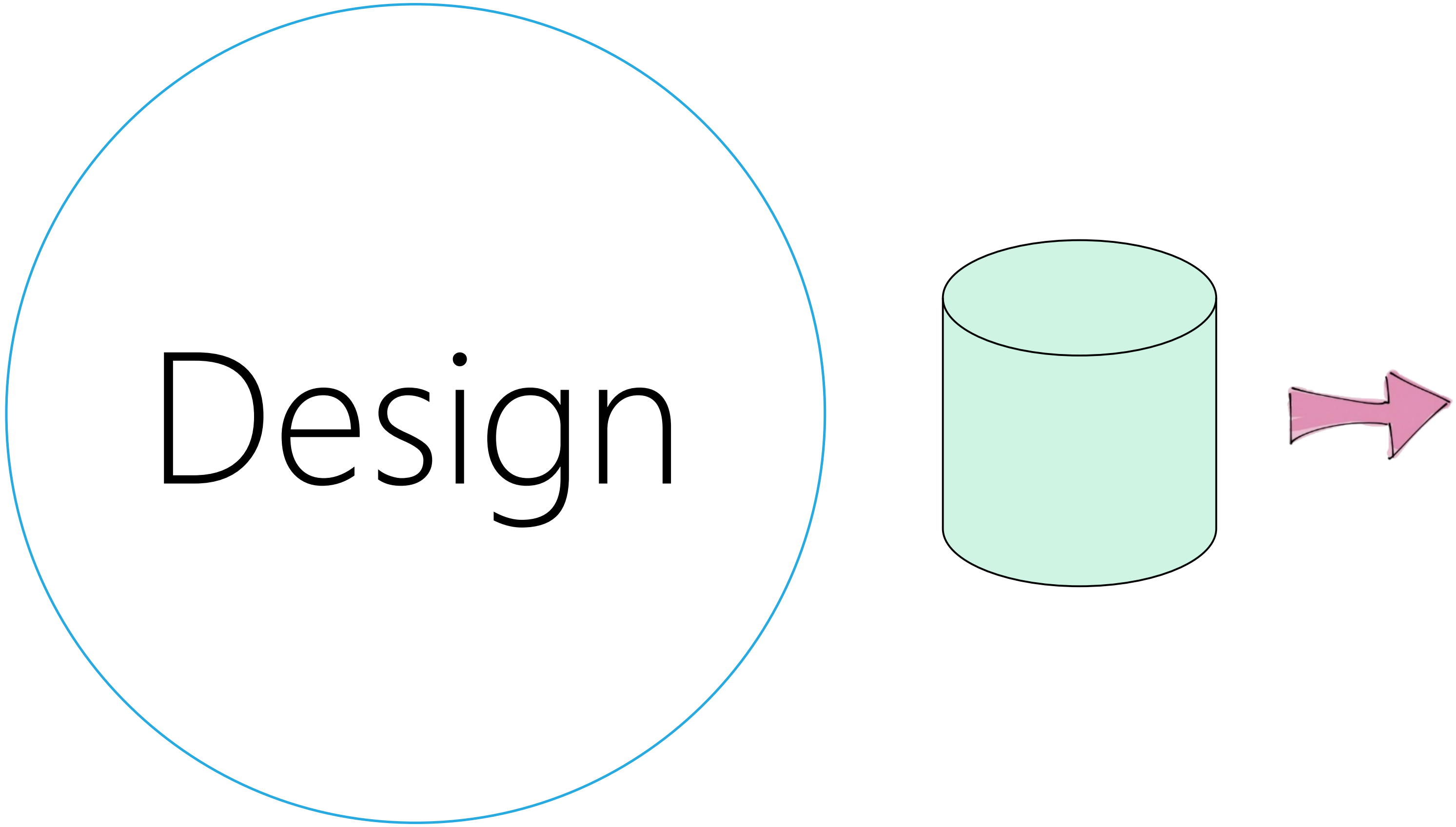
ARUP



A single source of the truth

No more ‘double handing’ of data

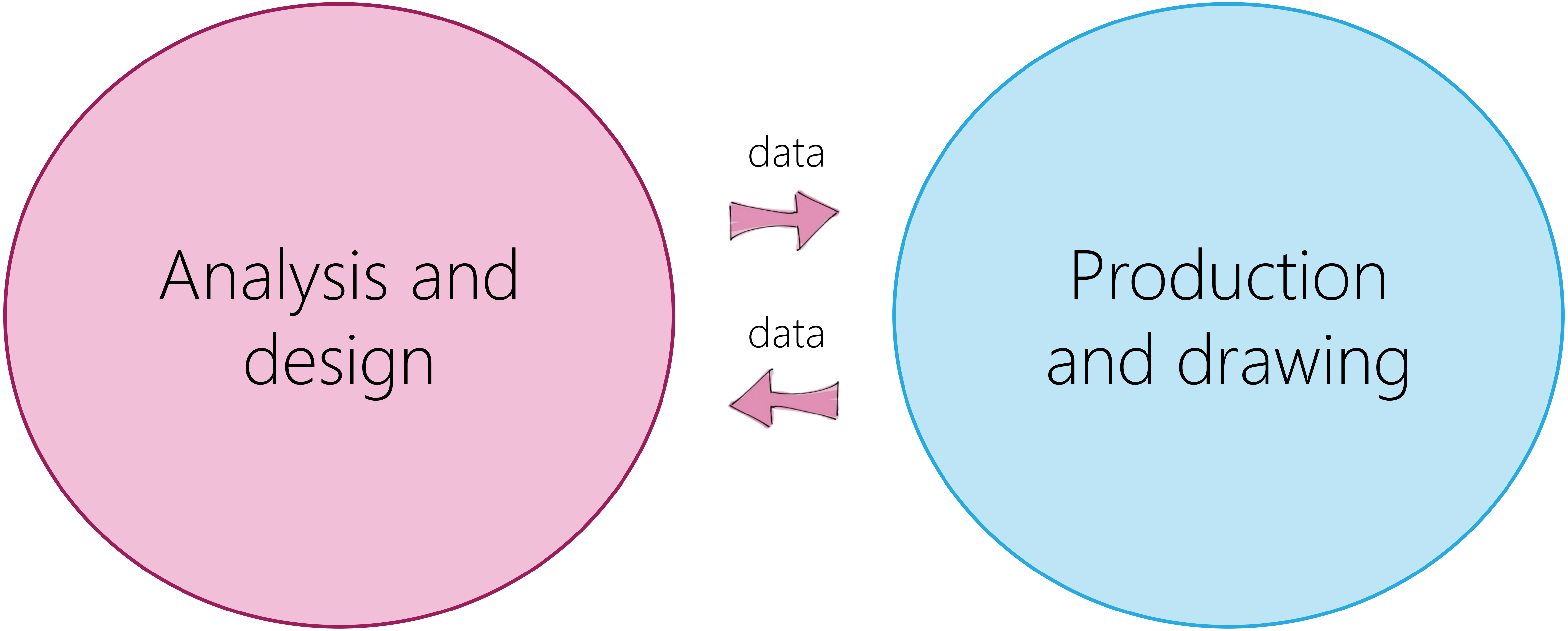
ARUP



Everything the client needs

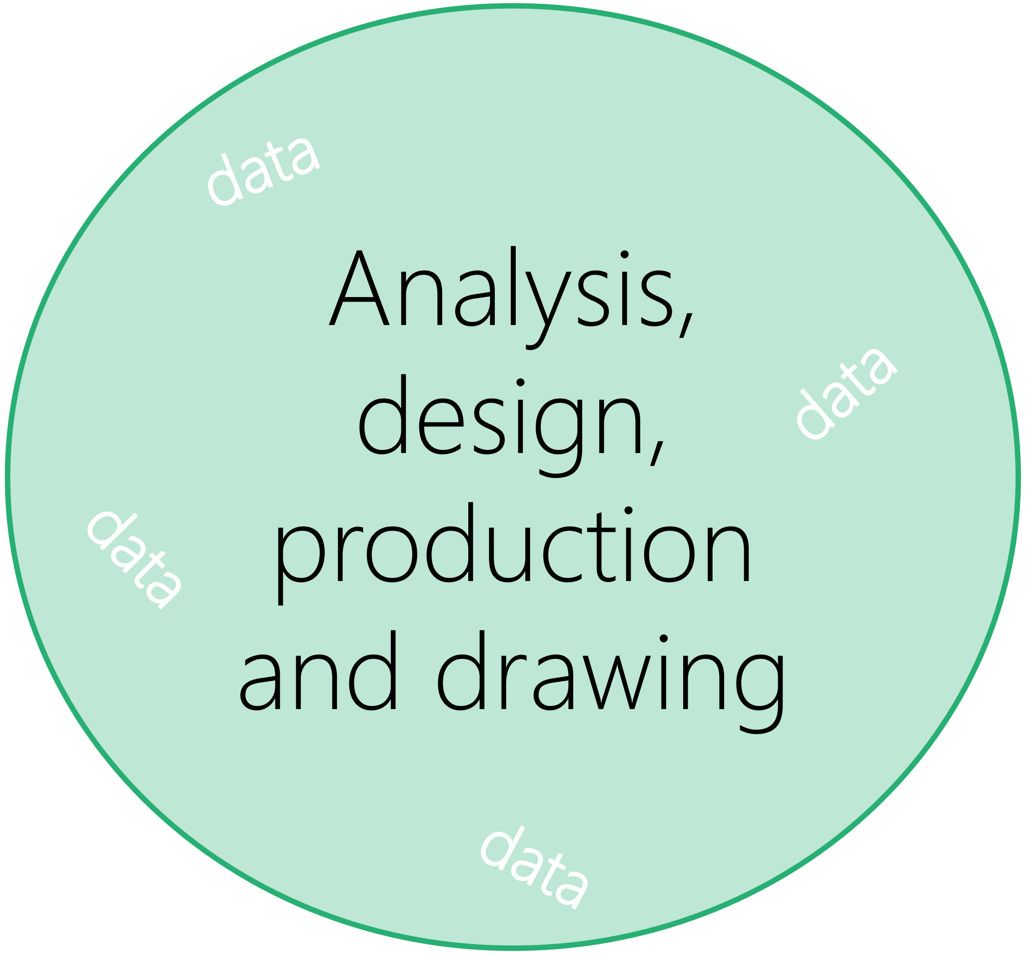
ARUP

Manual data transfer between two process streams ☹



ARUP

No data transfer in one flowing process stream

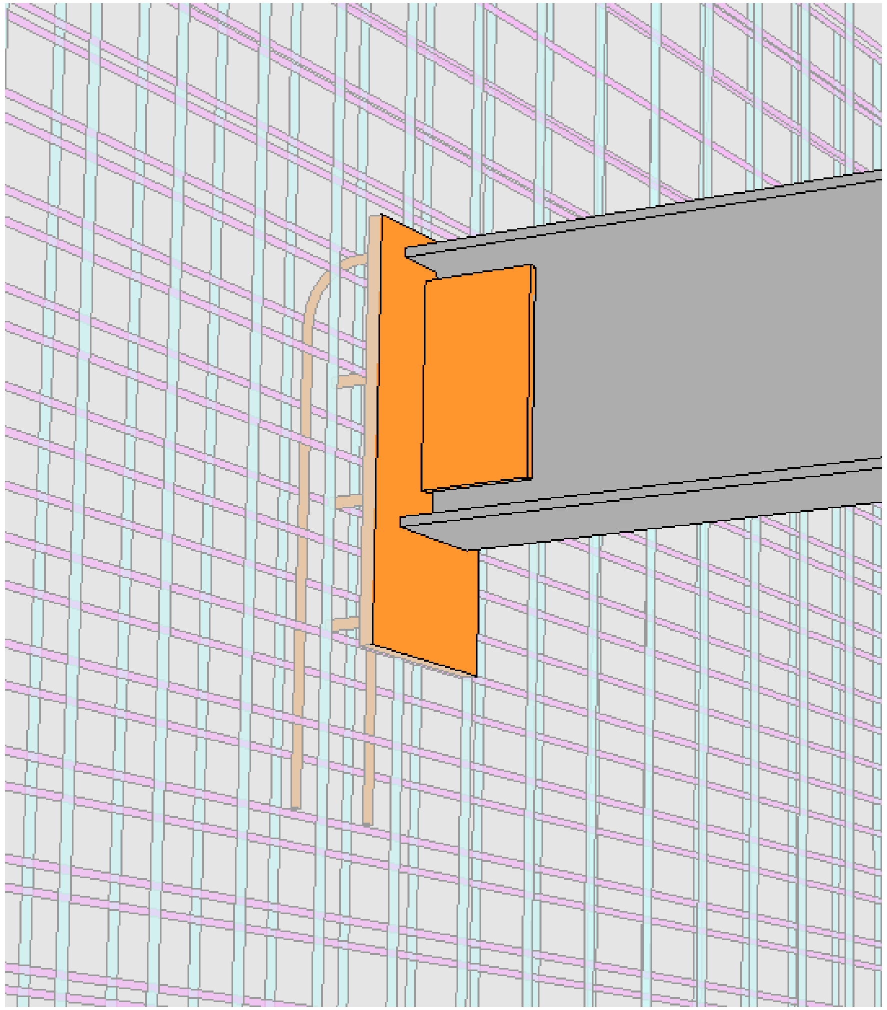


ARUP

Direct experience

1-Click virtual reality

Spot what 'looks wrong'



ARUP

Making time for thinking things through

ARUP

Improving

Adding to our engine

ARUP

"This couldn't get any better"

-Us

ARUP

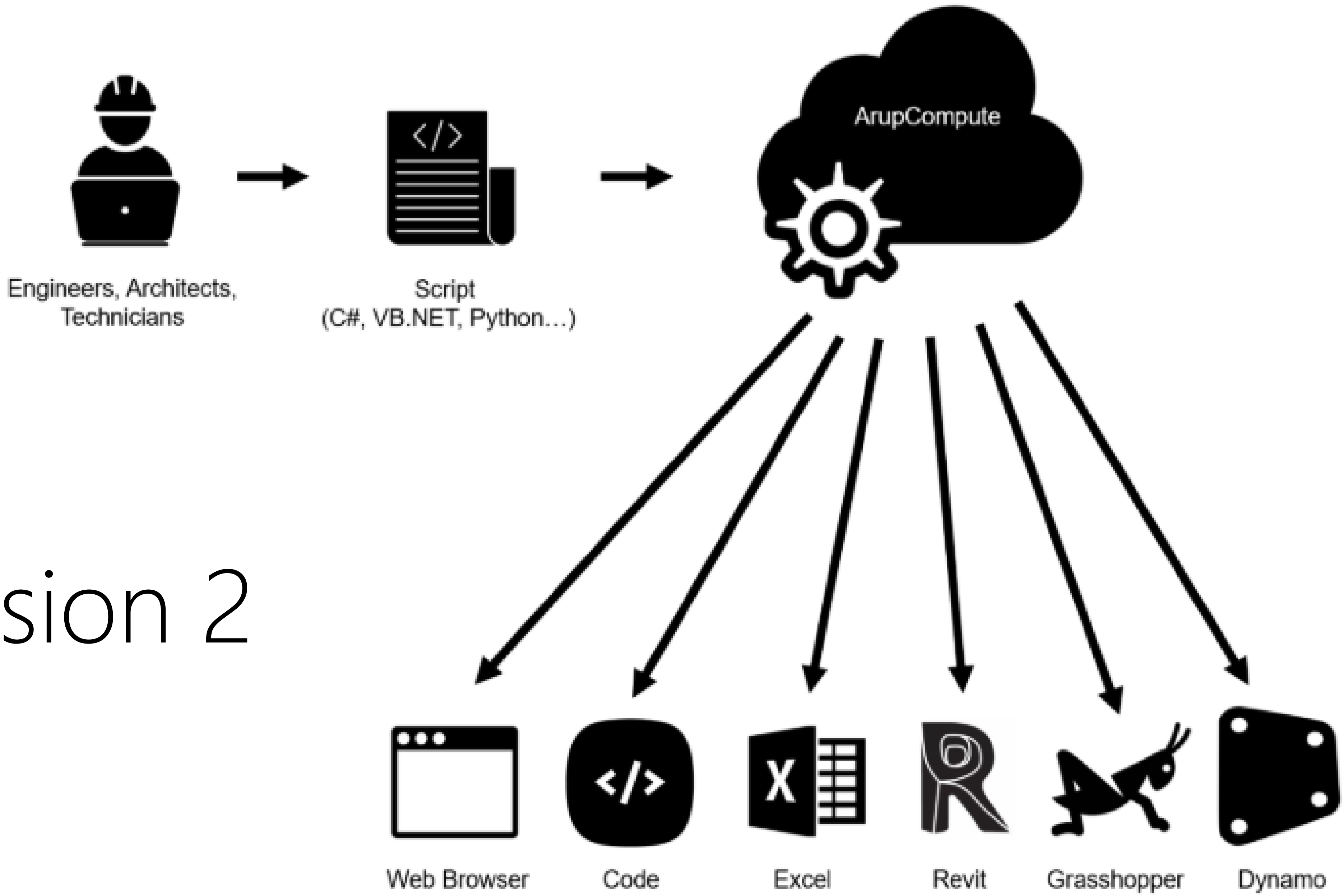
"Yeah it could"

Matteo Cominetti - People

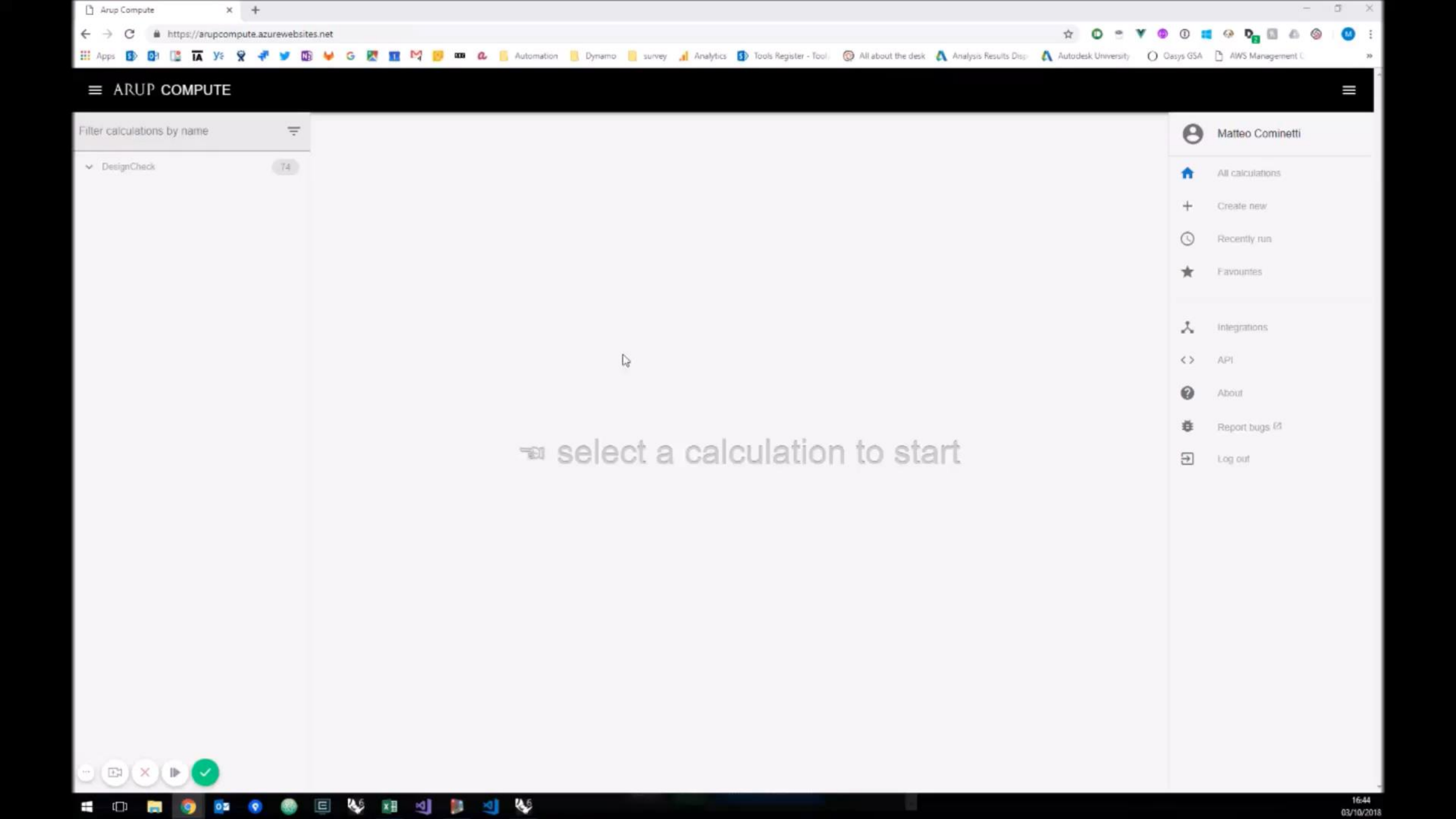
Senior Programmer

Digital Technology, London Office

...get an Arup photo Matteo!



Version 2
API


Arup Compute
https://arupcompute.azurewebsites.net
ARUP COMPUTE
Filter calculations by name
DesignCheck
74
Matteo Cominetti
All calculations
Create new
Recently run
Favourites
Integrations
API
About
Report bugs
Log out
select a calculation to start

The future

What’s next?

ARUP

Speckle integration?

Architect

Batch of changes

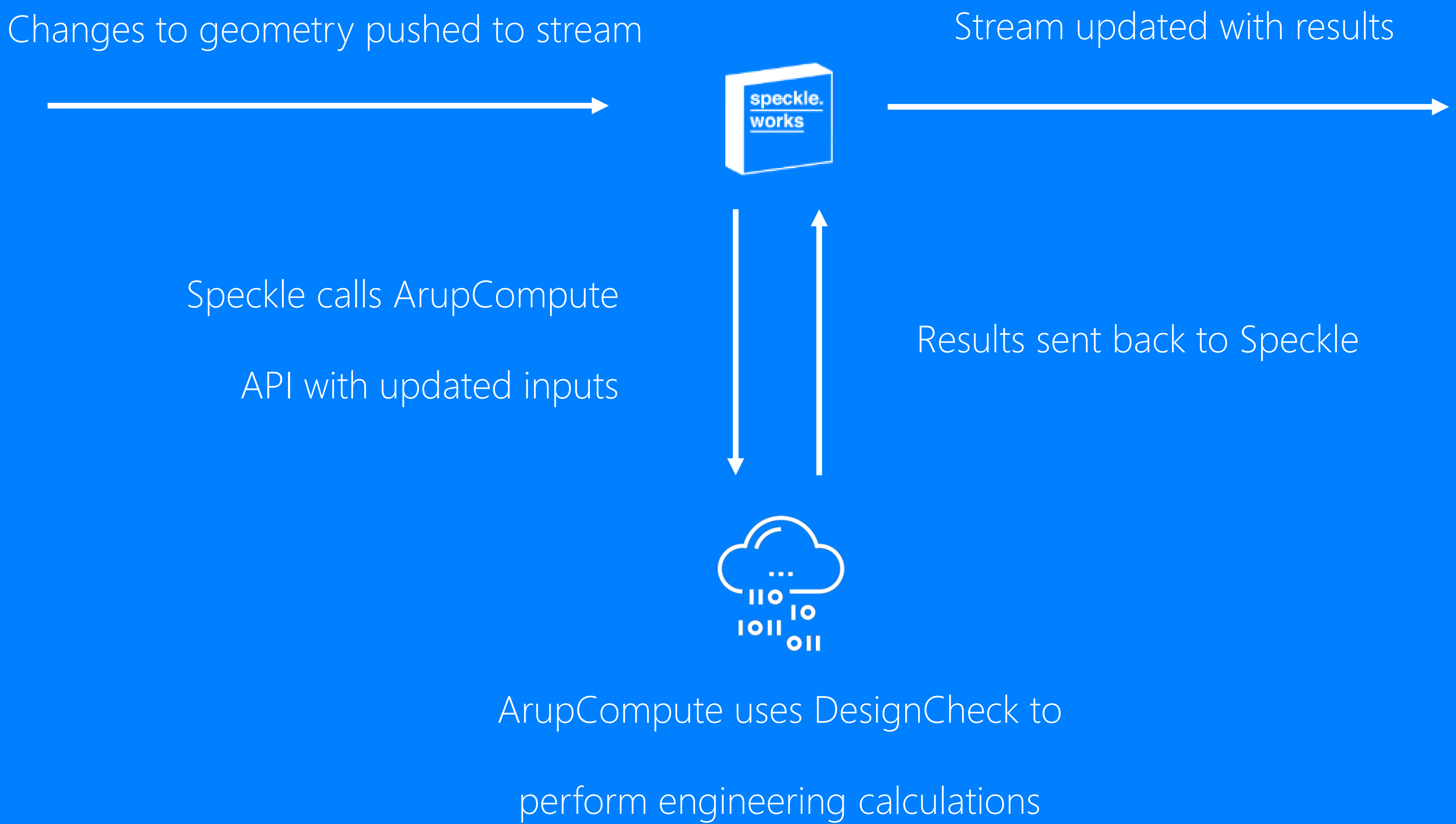
Engineer

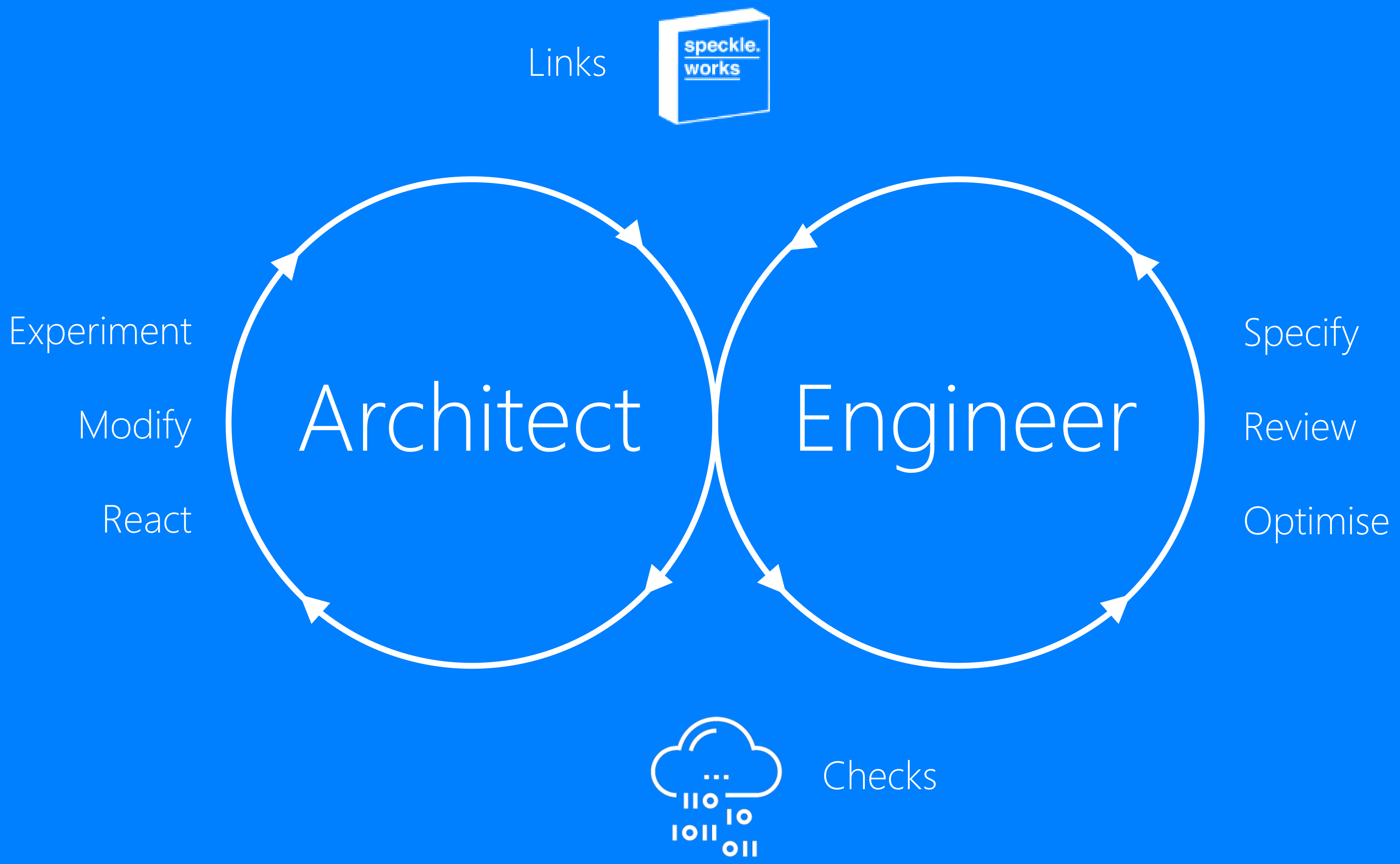
Check and comment

Architect

Batch of changes

Engineer


Changes to geometry pushed to stream
speckle.
works
Stream updated with results
Speckle calls ArupCompute
API with updated inputs
Results sent back to Speckle
110
10
1011
011
ArupCompute uses DesignCheck to
perform engineering calculations


Links
speckle.
works
Experiment
Modify
React
Architect
Engineer
Specify
Review
Optimise
Checks

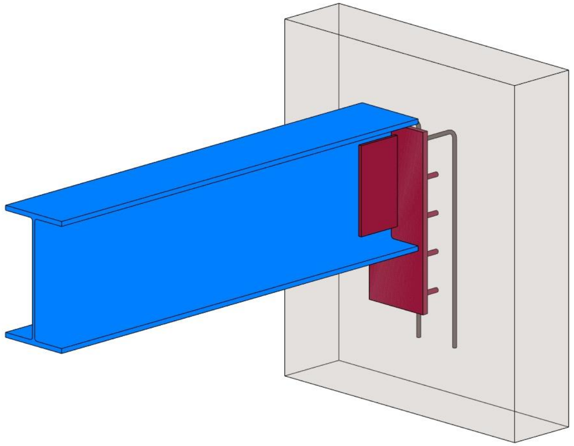
Data harvesting

Wolfram alpha

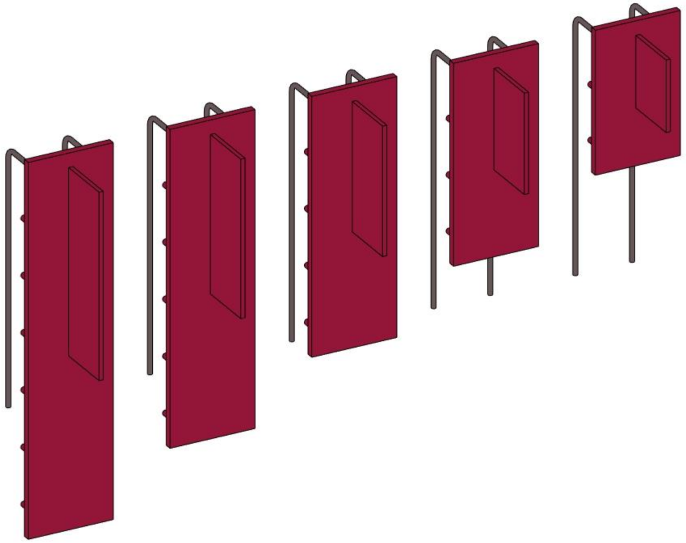
To conclude

If you only remember one bit

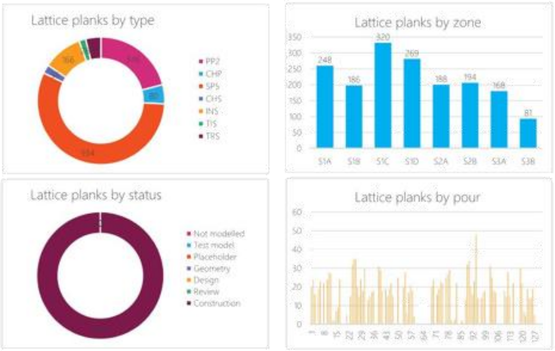
ARUP



Comprehensive and complete 3D modelling

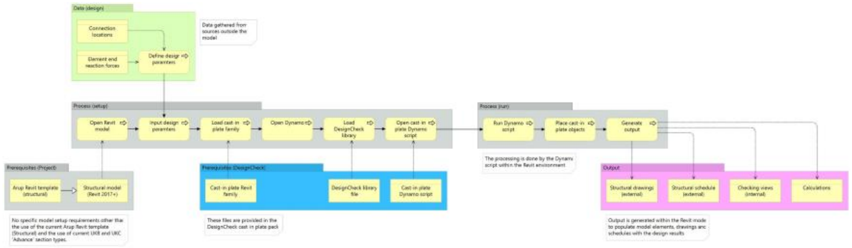


Complete accuracy and embedded information



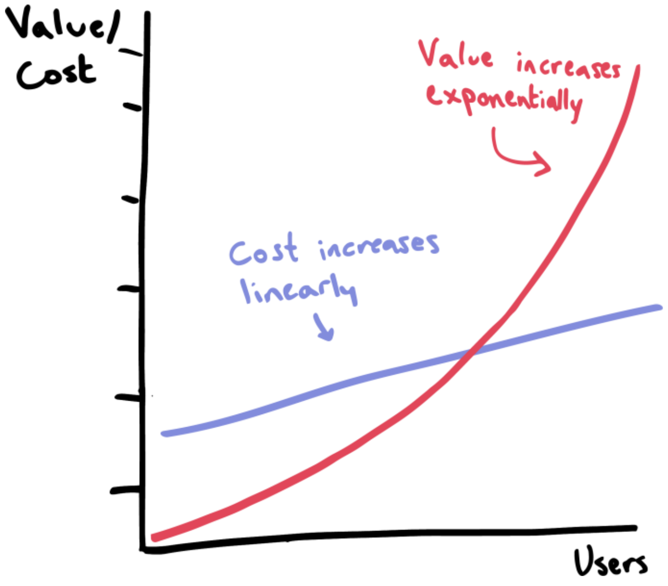
Better insight to improve our design and delivery

ARUP



Improve our processes and embrace automation

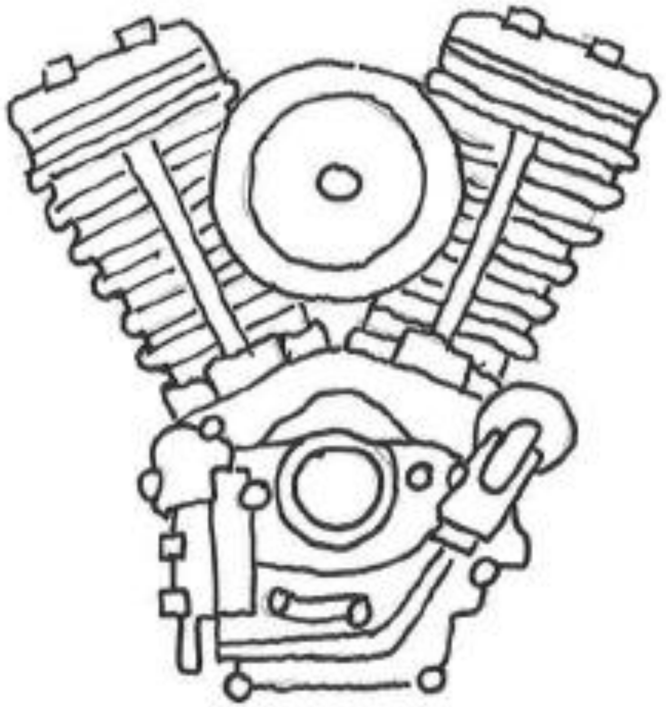
Use a single data environment to exercise control



Build and enhance digital toolsets that work for us

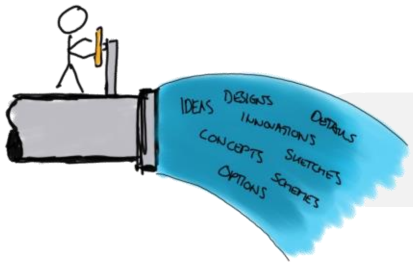
ARUP

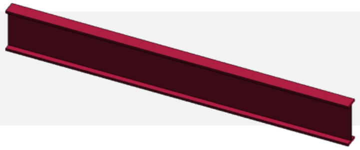
We took our engine...



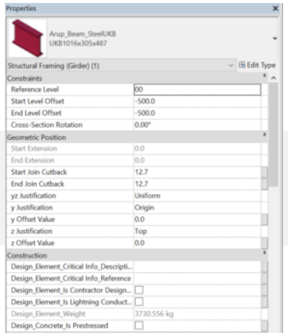
ARUP

...and built our process around it

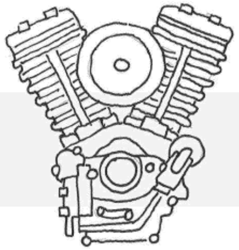




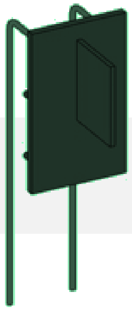
Geometry



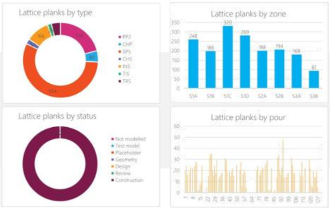
Parameters



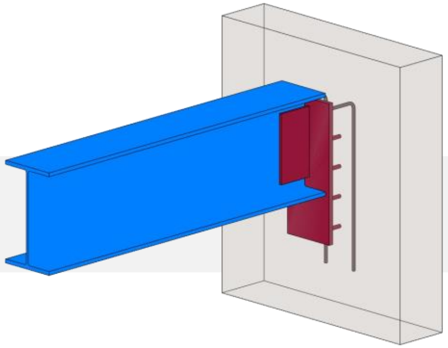
Calculation



Results



Insight



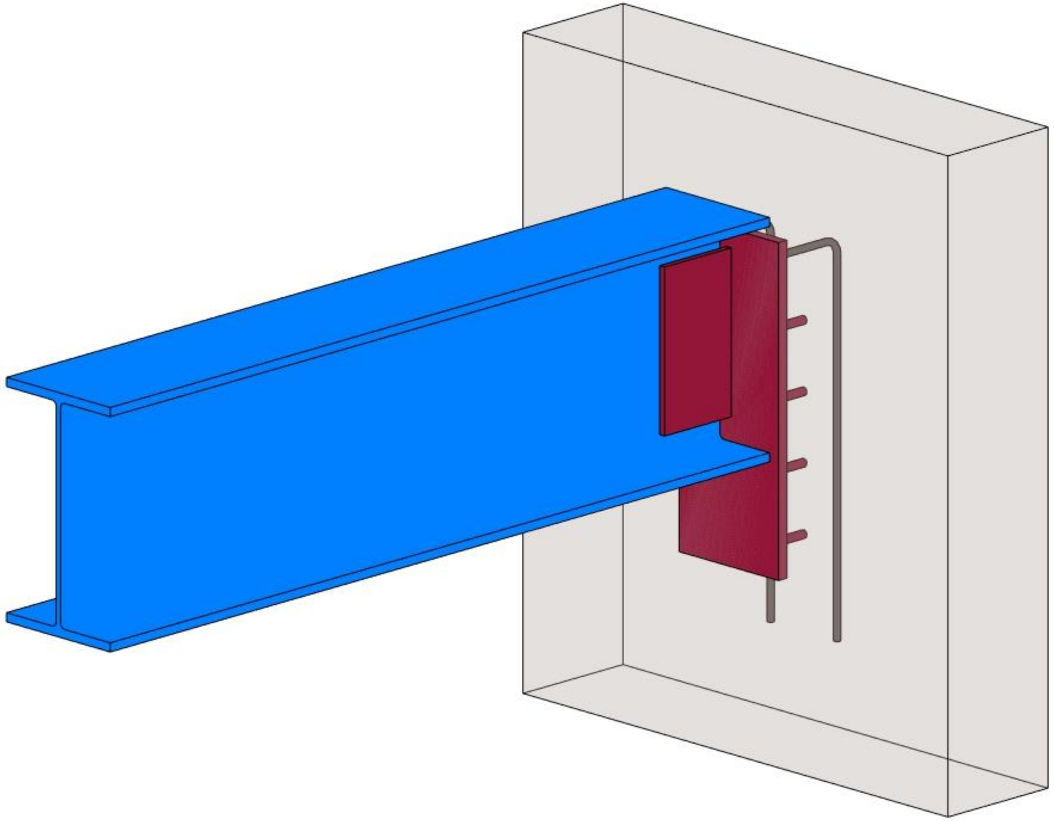
Communication

ARUP

"A late change in requirements is a competitive advantage."

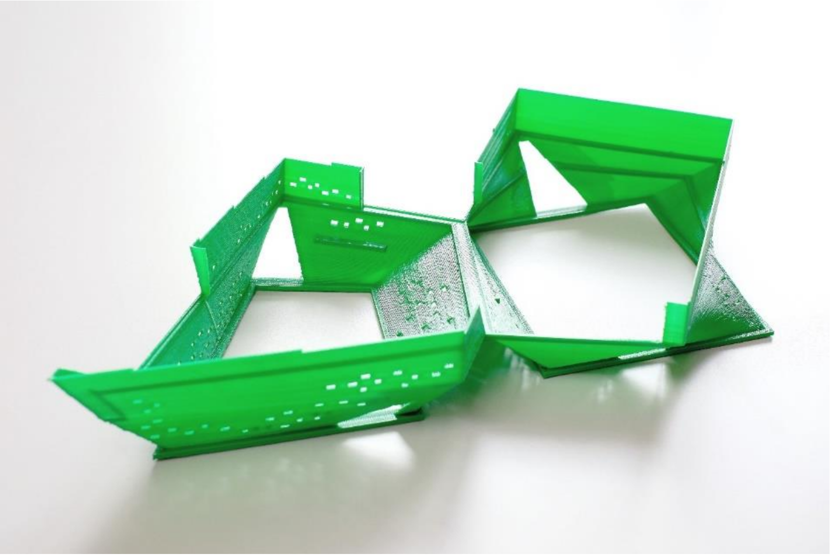
\- Mary Poppendieck.

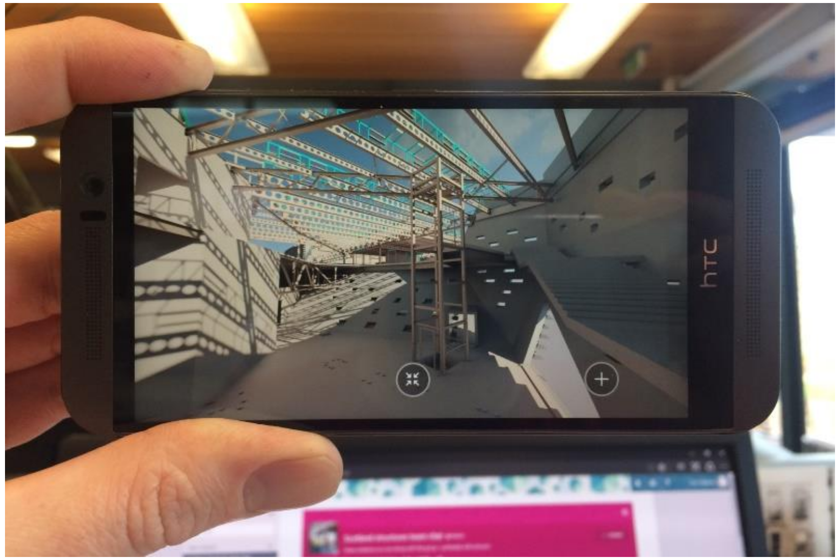
ARUP

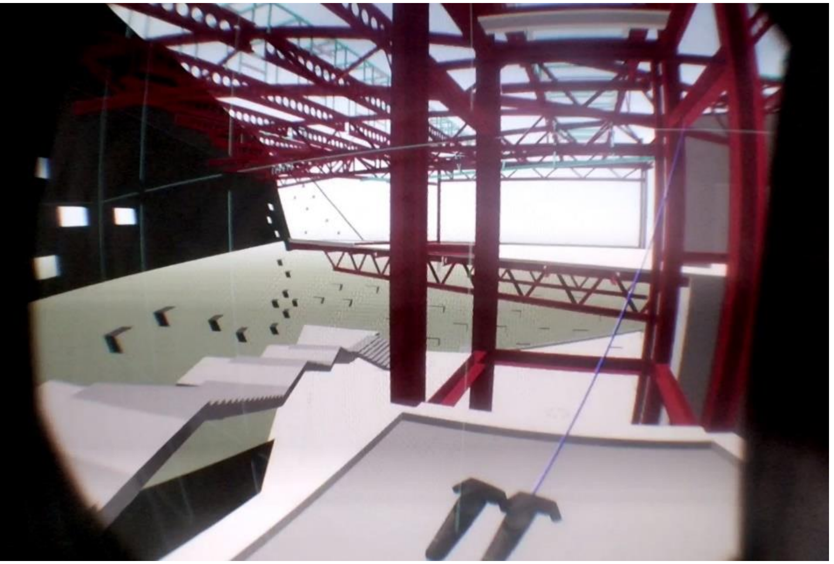


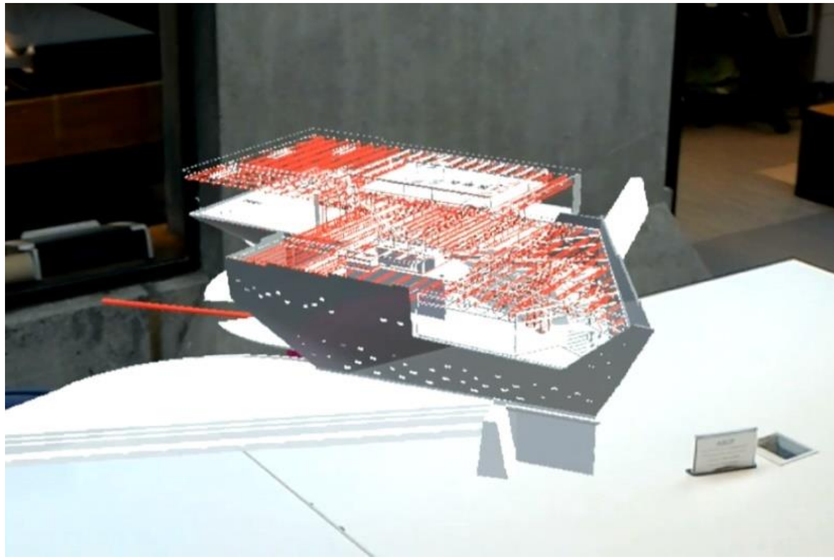
Design automation

ARUP









ARUP

Dynamo for Engineers, Design for All

Processes that work for us

Ian Wise | Senior Engineer | Arup

Steven Brown | Engineer | Arup

Hugh Groves | Engineer | Arup

ARUP