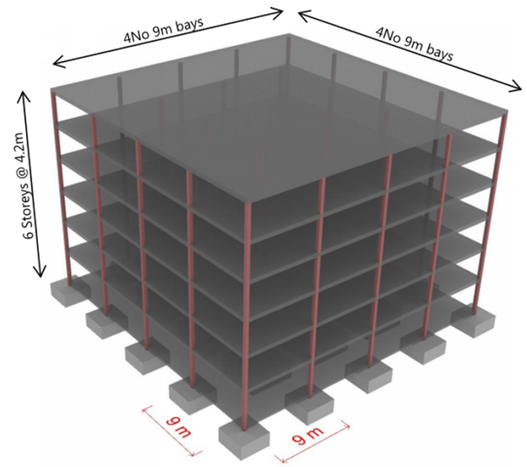
BUROHAPPOLD ENGINEERING



Embodied Carbon

Structural Sensitivity Study

3 April, 2020

This study has been developed to help structural engineers in our practice understand the impact of their design decisions on the embodied carbon of the resulting building. This piece of work is shared in the hope that it will provoke discussion and is not intended to provide design solutions!

It is more interested in sensitivity to design decisions (materials, grids etc) than absolute accuracy in the final figures.

As a baseline scheme we took a generic 8000m^2 six storey building with a 9m x 9m column grid designed for an imposed load of 4+1kN/m^2 and developed concrete, steel and timber solutions using the most conventional approach for each of these materials (concrete flat slab, composite steel beams with metal deck slabs and glulam beams with cross laminated timber slabs).

With these three baseline schemes we then studied the impact of changing each of the different design parameters in turn on the total embodied carbon.

These parameters included structural arrangement, loading, column grid, material specification, foundation type, structural system etc.

Finally, for each baseline scheme a series of parameters were changed together in steps to look at the potential total variation in embodied carbon that could be achieved within each system.

These included some option to get to very low embodied carbon values but these start to require compromises in structural depth, construction programme, column spacing and loading.

The overarching conclusion would appear to be that material choice has rather less impact on embodied carbon than concrete specification, grid choice and loadings.

This encourages us to focus harder on ensuring lean design and sensible grids whatever the material used.

Revision 08

Embodied Carbon - Routes to Reduction Study

The study consider a conventional office building for the following forms:

Concrete Flat Slab

331

Key Baseline Details

- 400mm Flat Slab
- 700x700 RC columns (2% reinf)
- 250mm thick Cores and Shear Walls
- C32/40 Concrete

Composite Slab on Steel

227

Key Baseline Details

- 120mm Comflor 51 Composite Slab
- 686UB125 Primary Beams
- 533UBx82 Secondary beams (Composite) at 3m c/c
- 356UC235 Columns
- 250mm thick RC Cores and Steel flat braced bays
- S355 Steel, C32/40 Concrete

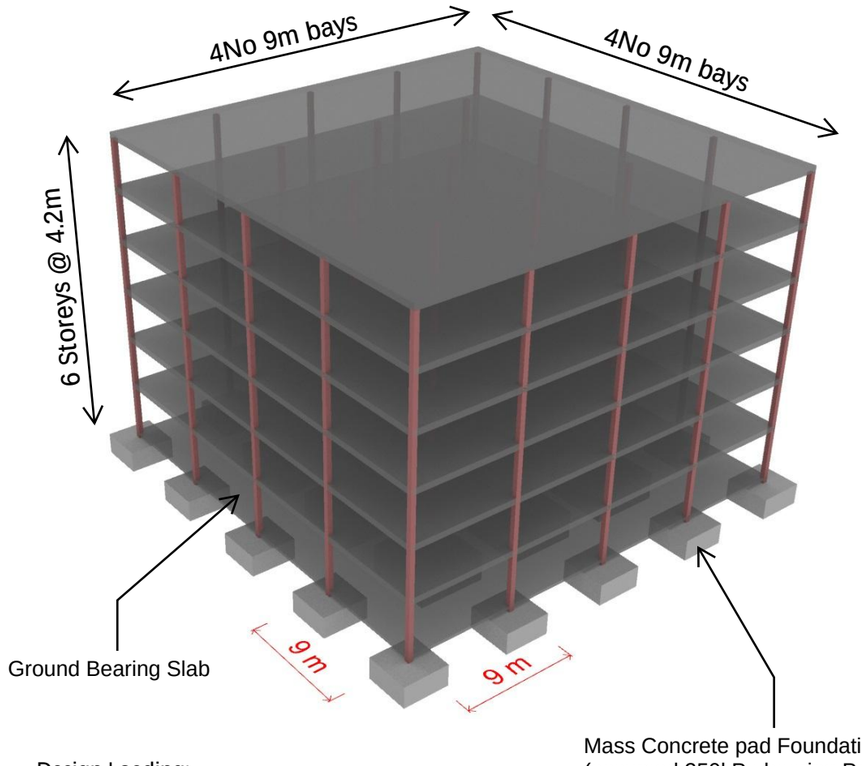
CLT on Glulam

142

Key Baseline Details

- 100mm thick CLT Slab
- Glulam primary beams 1000mm deep
- Glulam secondary beams at 3m c/c 800mm deep
- Glulam columns 480 x 1000mm
- 250mm thick RC Cores and Steel flat braced bays
- GL24H grade Glulam
- C32/40 Concrete

Common Design Parameters



Design Loading:

Dead:	Self Weight of Structure	
Superimposed Dead:	Ceiling and Services	0.5 kN/m2
	Access Floor + Finishes	1.0 kN/m2
Imposed Load:	Office Loading	4.0 kN/m2
	Moveable Partitions	1.0 kN/m2

Serviceability

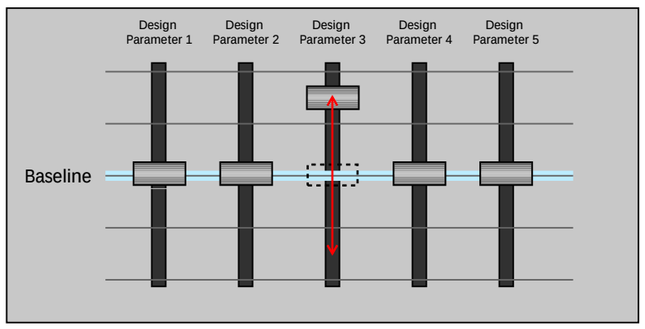
Deflections to Code - but < 20mm

Natural Frequency <4Hz

Fire Resistance

60minutes Fire resistance

For each of the above systems each key design parameter has been individually varied from the baseline in turn and the new EmbCO_2e value recalculated.



Embodied Carbon Figures are for Superstructure and Substructure only.

They are based on Cradle to Gate values (Modules A1-A3)

They use the ICE Carbon Data for the UK.

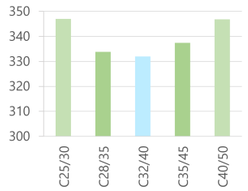
BUROHAPPOLD ENGINEERING	Project: Embodied Carbon System Parameter Study		Project Number: 00XXXX	Status: FOR GUIDANCE	
	Sketch Title:		Sketch Number:	Date: 13/02/20	Initials: HG / Revision: 0005

Embodied Carbon Routes to Reduction - Concrete Frame

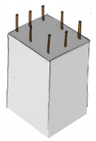
Embodied Carbon kgCO2e / m2

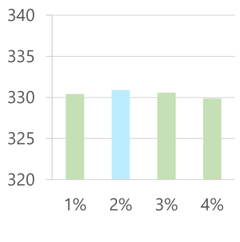
350
300
250
200

331 Baseline Scheme



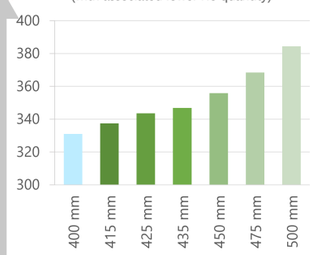
Concrete Grade 345





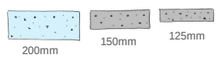
Column Reinforcement %

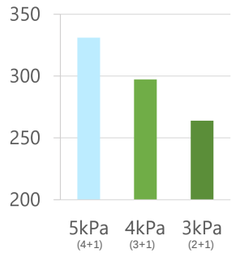
385 Floor Slab Thickness
(with associated lower RC quantity)



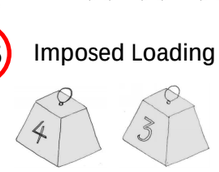
331

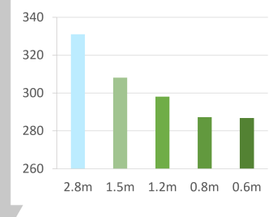
Ground Slab Thickness 325



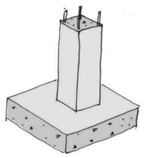


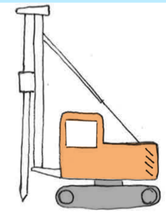
265 Imposed Loading



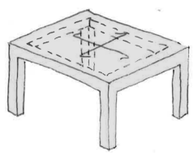


285 Pad Foundation Thickness
RC instead of Mass



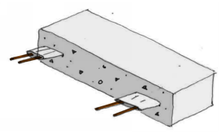


285 Piled Foundation
4No 750mm CFA Pile Caps

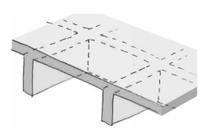


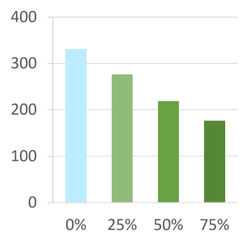
Beam & Slab 245
230mm slab on
700 x 600 beams on grid

Post Tensioned Slab 235
260mm thick

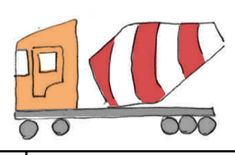


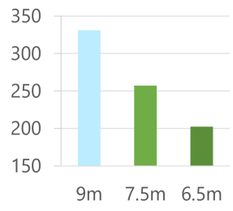
Waffle Slab 190
400mm thk with 150mm ribs @ 900mm c/c



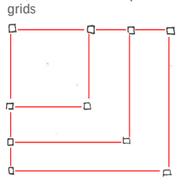


GGBS Content 175





200 Column Grid
9m, 7.5m and 6.5m square grids



Design Parameter

NB Only one parameter varied at a time For each option building is redesigned fully for the revised loads, grade etc.

KEY

= Baseline EmbC02 value

= Change from Baseline for single parameter variation

Design Parameter XXX

XXX = Min/Max Embodied Carbon ($kgCO^2e/m^2$)

= Variation in EmbCO2 for different parameter values

BUROHAPPOLD ENGINEERING	Project: Embodied Carbon System Parameter Study	Project Number: 00XXXX	Status: FOR GUIDANCE
	Sketch Title:	Sketch Number:	Date: 13/02/20 / Initials: HG / Revision: 0005

Embodied Carbon Routes to Reduction - Steel Frame

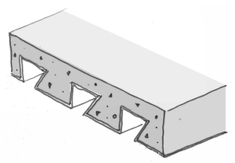
Embodied Carbon kgCO2e / m2

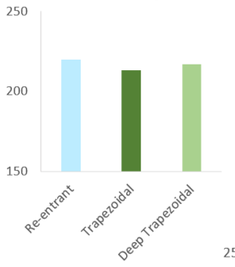
250 · 200 · 150 · 100

227 Baseline Scheme

Composite Deck Profile — 215

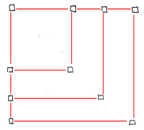
ComFlor 51, 60 and 80, spanning 3m.





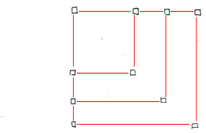
9m x 12m Grid — 246

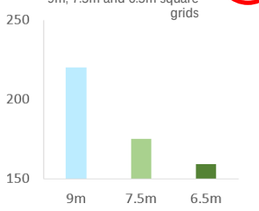
9m x 12m grid with 4 composite deck spans/ bay in the 12m direction



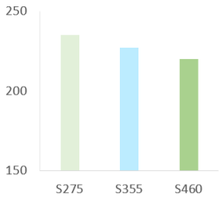
Column Grid — 160

9m, 7.5m and 6.5m square grids

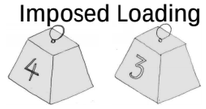


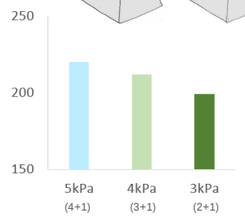


Steel Grade — 220



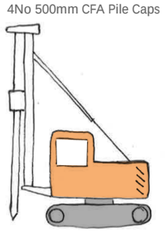
Imposed Loading — 200





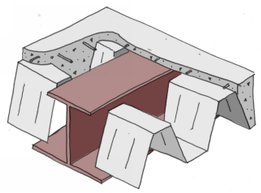
Piled Foundation — 160

4No 500mm CFA Pile Caps



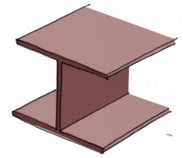
SlimFlor — 270

310mm thick ComFlor 210 to match ASB depth



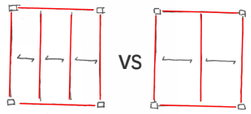
UC Beams — 290

UC 356x406 primary + UC 356x368 secondary



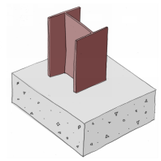
Secondary Beam Spacing — 215

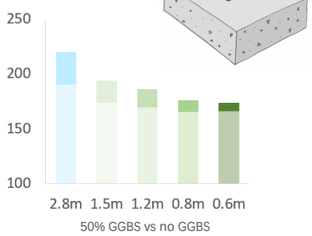
Three 3m spans vs two 4.5m spans



Pad Foundation Thickness — 175

RC instead of Mass

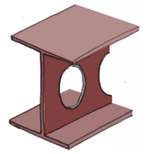




50% GGBS vs no GGBS

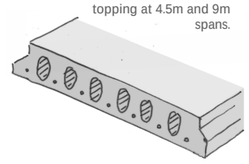
Cellular Beams — 220

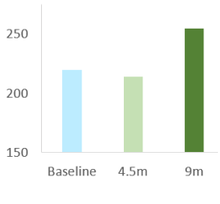
Westok Cellular Beams 2 x UB 686x254 primary + 2 x UB 457x191 secondary w/ 300mm dia. holes, 450mm c/c



PreCast Hollowcore — 215

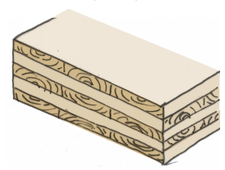
Composite, 150mm thick with 75mm structural topping at 4.5m and 9m spans.





CLT Deck — 145

160mm thick, 5 laminations spanning 3m.



KEY

- = Baseline EmbC02 value
- Design Parameter (XXX) = Change from Baseline for single parameter variation
- XXX = Min/Max Embodied Carbon ($kgCO^2e/m^2$)
- = Variation in EmbCO2 for different parameter values

Design Parameter

NB Only one parameter varied at a time For each option building is redesigned fully for the revised loads, grade etc.

BUROHAPPOLD ENGINEERING	Project: Embodied Carbon System Parameter Study		Project Number: 00XXXX	Status: FOR GUIDANCE	
	Sketch Title:		Sketch Number:	Date: 13/02/20	Initials: HG / Revision: 0005

Embodied Carbon Routes to Reduction - Timber Frame

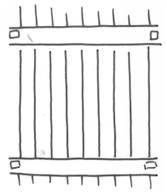
Embodied Carbon kgCO2e / m2

150

100

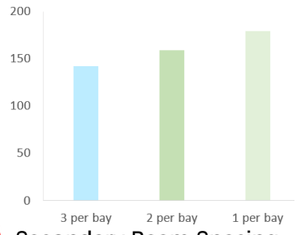
Solid timber — 191

1050mm x 520mm Glulam beams on a 9m x 9m grid. 430mm x 200mm green Douglas Fir joists supporting a plywood deck.



KEY

- = Baseline EmbC02 value
- = Change from Baseline for single parameter variation (Design Parameter XXX)
- XXX = Min/Max Embodied Carbon ($kgCO^2e/m^2$)
- = Variation in EmbCO2 for different parameter values



142 Secondary Beam Spacing

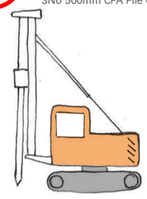
3m (3 spans per bay), 4.5m (2 spans per bay) and 9m (1 span per bay).

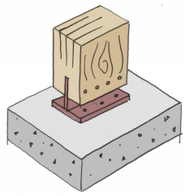
142 Baseline Scheme

Plasterboard Fire proofing adds 8kgCO2e/m2

135 Piled Foundation

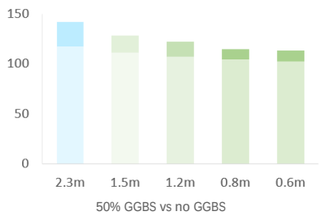
3No 500mm CFA Pile Caps





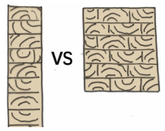
Pad Foundation Thickness — 110

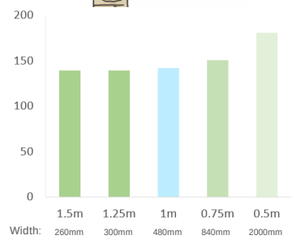
RC instead of Mass



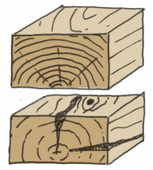
140 Beam Depth

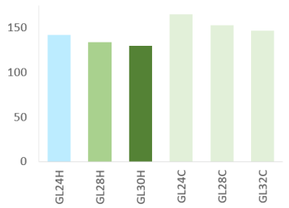
Limiting beam depth and adjusting width to suit



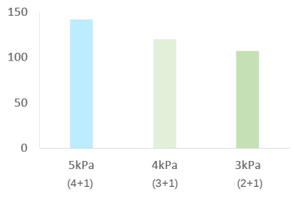


130 Glulam Grade



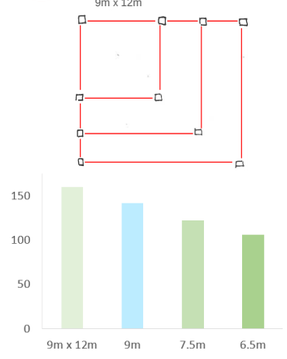


Imposed Loading — 105



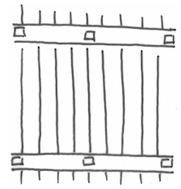
105 Column Grid

9m, 7.5m and 6.5m square grids + 9m x 12m



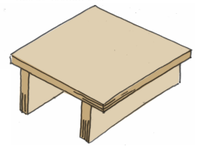
Solid timber - 9m x 3.75m grid — 135

Reducing grid size to allow consistent size of 430mm x 200mm for primary beams and joists, all in green Douglas Fir.



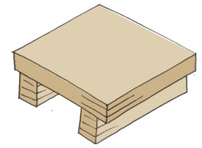
LVL Rib — 120

39mm deck with 400mm deep ribs at 400mm c/c.



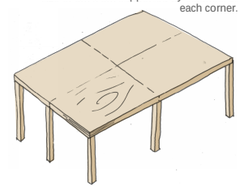
CLT + Glulam Rib — 130

90mm deck with 350mm deep ribs at 600mm c/c.



CLT Flat slab — 80

CLT slabs at maximum commonly available size of 3m x 5m supported by columns at each corner.

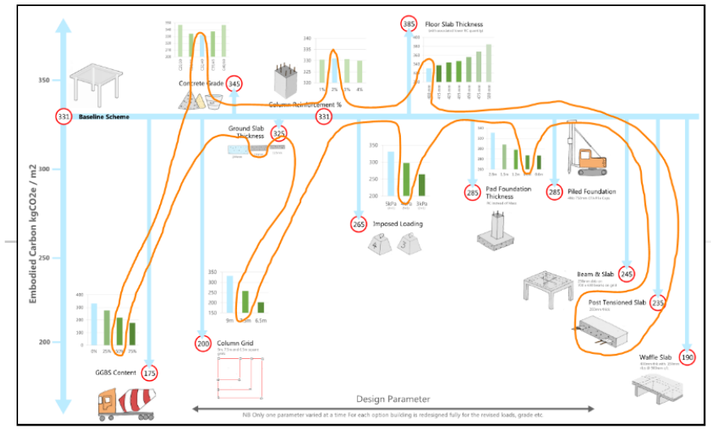


Design Parameter

NB Only one parameter varied at a time For each option building is redesigned fully for the revised loads, grade etc.

BUROHAPPOLD ENGINEERING	Project: Embodied Carbon System Parameter Study		Project Number: 00XXXX	Status: FOR GUIDANCE	
	Sketch Title:		Sketch Number:	Date: 13/02/20	Initials: HG / Revision: 0005

Embodied Carbon Routes to Reduction - Combined Parameters



The values below represent possible $EmbCO_2e$ values when several of the parameters are combined together as per the example above. The main changes between each example are noted below.

Embodied Carbon kgCO2e / m2

300

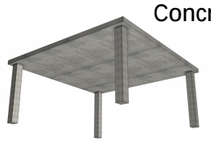
200

100

0

Concrete Base Scheme

331



136 + Reduced Load
As above with 4kPa imposed loading

113 + 7.5m grid
As above with 7.5m square grid

77 + Most efficient floor system
Waffle slab, 300mm thick overall with 150mm thick ribs on 900mm c/c and 100mm thick slab in between on a 7.5m square grid with 4kPa imposed loading, C32/40 concrete and 0.6m thick RC pad foundations with 50% GGBS

54 Minimum CO_2e scheme
Waffle slab, 270mm thick overall with 150mm thick ribs on 900mm c/c and 100mm thick slab in between on a 6.5m square grid with 3.5kPa imposed loading, C32/40 concrete and 0.6m thick RC pad foundations with 70% GGBS

- 270mm Struc Zone
- Waffle Slab
- 6.5m Column Grid
- (2.5+1)kPa Imposed loading
- 70% GGBS

201 Foundations and Material Grade
Baseline parameters with 0.6m thick RC pad foundations with 50% GGBS and C32/40 Concrete

Steel Base Scheme

227

133 Foundations and Material Grade
Baseline parameters with 0.6m thick RC pad foundations with 50% GGBS and S460 Steel grade

131 + Reduced Load
As above with 4kPa imposed loading

102 + 7.5m grid
As above with 7.5m square grid

92 + Most efficient floor system
Comflor CF60 trapezoidal composite deck spanning 3.75m on a 7.5m square grid with 4kPa imposed loading, S460 Steel grade and 0.6m thick RC pad foundations with 50% GGBS

66 Minimum CO_2e scheme
Comflor CF60 trapezoidal composite deck spanning 3.25m on a 6.5m square grid with 3.5kPa imposed loading, S460 Steel grade and 0.6m thick RC pad foundations with 70% GGBS

- 525mm Struc Zone
- 6.5m Column Grid
- (2.5+1)kPa Imposed loading
- 70% GGBS

Steel/Timber hybrid

62

120mm thick CLT deck spanning 3.25m on a 6.5m square grid with 3.5kPa imposed loading, S460 Steel grade and piled foundations with 70% GGBS

- 525mm Struc Zone
- CLT on Steel
- 6.5m Column Grid
- (2.5+1)kPa Imposed loading
- 70% GGBS

Timber Base Scheme

142

* Plasterboard fire proofing adds 8 kgCO2e/m2

88 Foundations and Material Grade
Baseline parameters with 0.6m thick RC pad foundations with 50% GGBS and GL30H Glulam grade

78 + Reduced Load
As above with 4kPa imposed loading

75 + 7.5m grid
As above with 7.5m square grid

47 + Most efficient floor system
Glulam and CLT rib deck spanning 7.5m with 4kPa imposed loading, GL30H glulam and 0.6m thk RC pad foundations with 50% GGBS

41 Minimum CO_2e scheme
LVL rib deck spanning 6.5m with 3.5kPa imposed loading, GL30H glulam and 0.6m thick RC pad foundations with 70% GGBS

- 710mm Struc Zone
- LVL RibDeck on Glulam
- 6.5m Column Grid
- (2.5+1)kPa Imposed loading
- 70% GGBS

BH Embodied Carbon Rating

G
F
E
D
C
B
A

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BUROHAPPOLD ENGINEERING

Part of Buro Happold's ongoing Embodied Carbon Research to achieve our climate emergency commitments

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