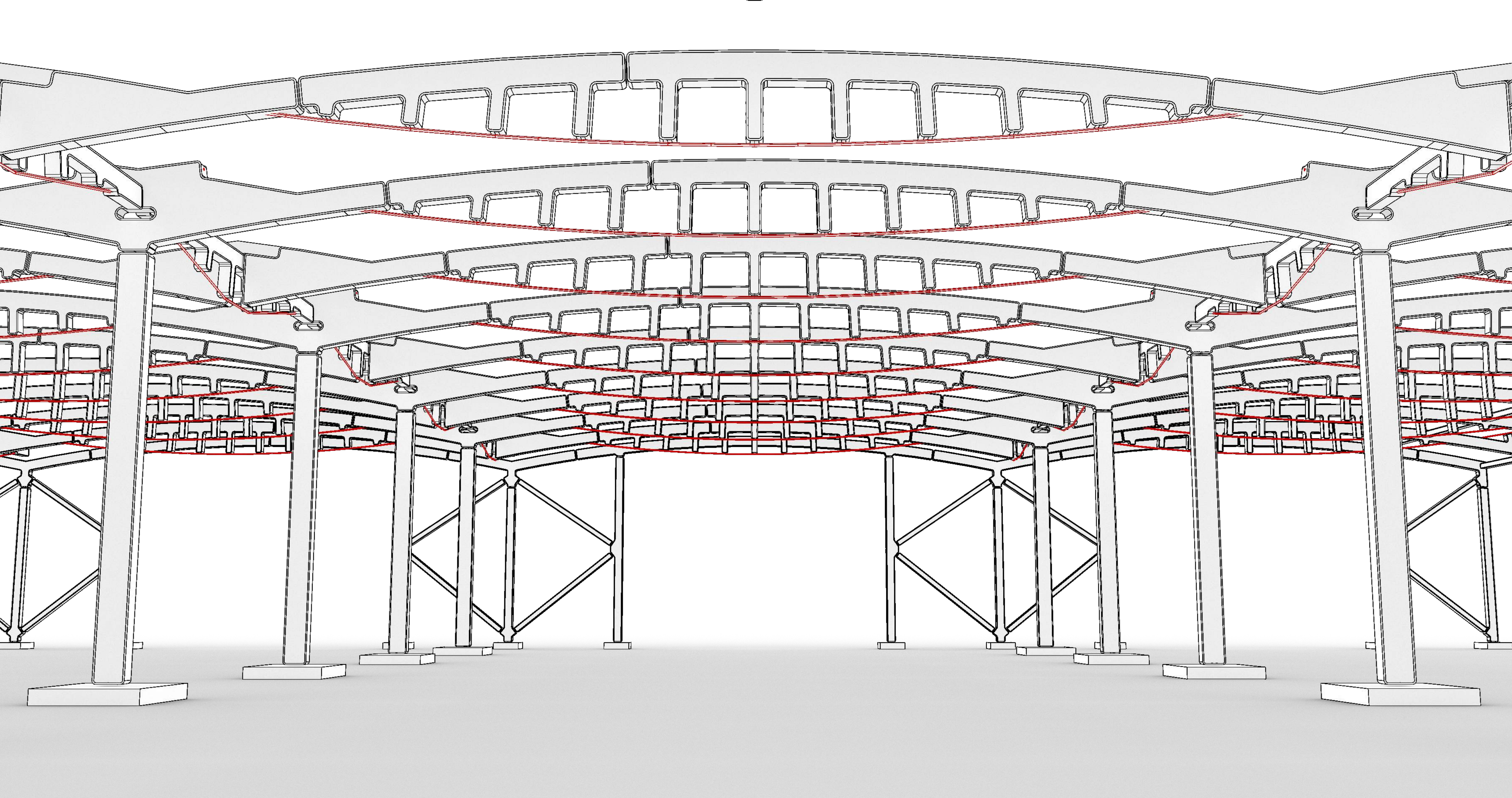


minimass portal frame warehouse
36m x 15m grid case study

minimass™

minimass™

Contents

status: for information
date: 28/01/2025
by: ARC
rev: 00

confidential

1.0 Summary

The long-span portal frame is an important type of structure for the warehouse, industrial and data centre sectors. The purpose of this document is to describe how a minimass portal frame can be used and the benefits this can bring.

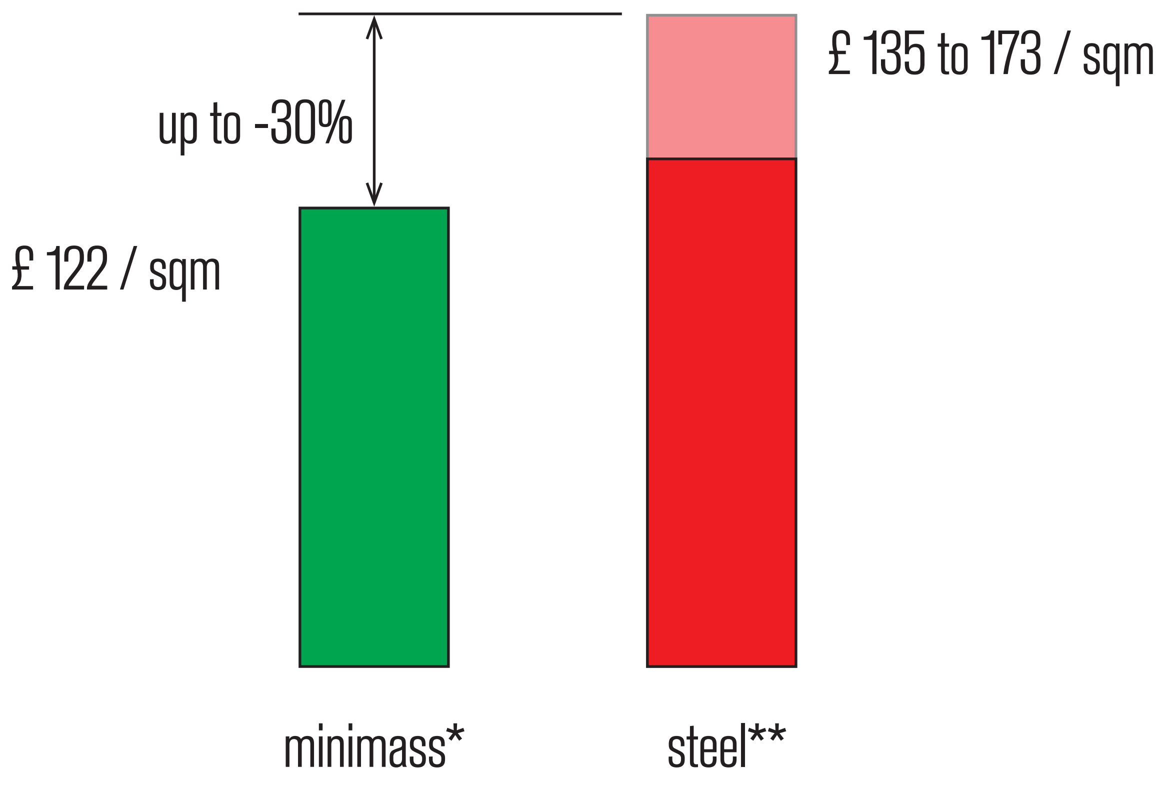
This report details a case study building with four bays of 36m in one direction and 7 bays of 15m in the other direction, giving a total floor area of 15,120 sqm. It is a typical long-span industrial building, with a single storey and an eaves height of 12m. This sector is currently dominated by structural steel frames (in the UK), so all comparison numbers are based on freely available, up-to-date cost estimation data (refer to the appendix for further details). This shows that the current market standard for this size of building is a steel frame that weighs 45kg / sqm and has a cost ranging from £135 to £173 / sqm. Taking standard assumptions for embodied carbon, stages A1-A5w, this structural steel frame would include 80kg CO2e / sqm.

We have shown that it is possible to achieve the same area, performance requirements and programme by using concrete with the minimass design approach. The result is a structure that works in the same way as structural steel - it has long-span portal frames, columns on a hit-and-miss grid, high eaves and frame elements in the perimeter structure to enable multiple large openings for access, loading etc. The minimass version has a cost (supply and installation) of £122 / sqm and a value of embodied carbon (A1-A5w) of 45 kg /sqm. That equates to a cost saving of up to 30% and a carbon saving of up to 44%. These are big numbers - if a typical "build-to-suit" warehouse has an area of 31,000 sqm (333,000 sq ft) then the project saving could amount to up to £1.5m by switching to minimass.

However, we understand that there is risk involved in using a new approach, e.g. from aspects related to erection of the frame. We encourage readers to get in touch with us directly to discuss potential pilot projects. These could range from individual buildings at a smaller scale, to one or several bays within a larger building that is predominantly built from steel. Together, we can unlock the savings promised by this game-changing innovation.

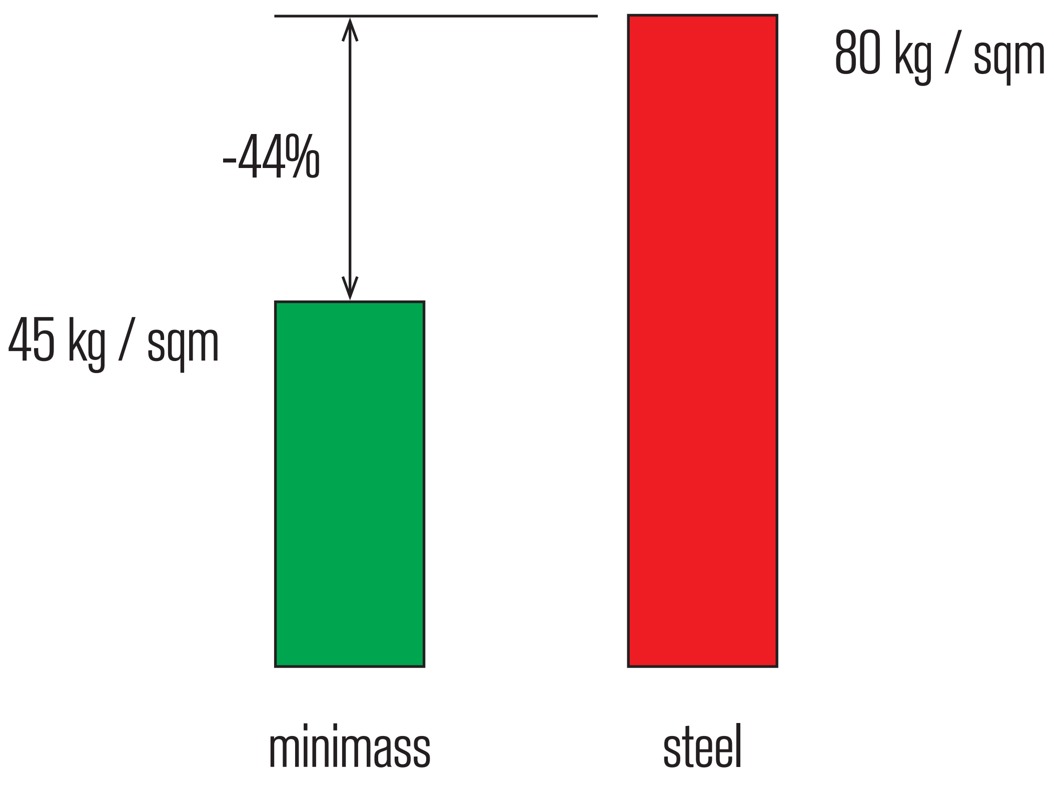
For more information about minimass, please refer to our website, www.minimass.net

2.0 Cost & carbon comparison



Cost

10% to 30 % saving



Carbon

44% saving

* includes supply of elements, connections and installation

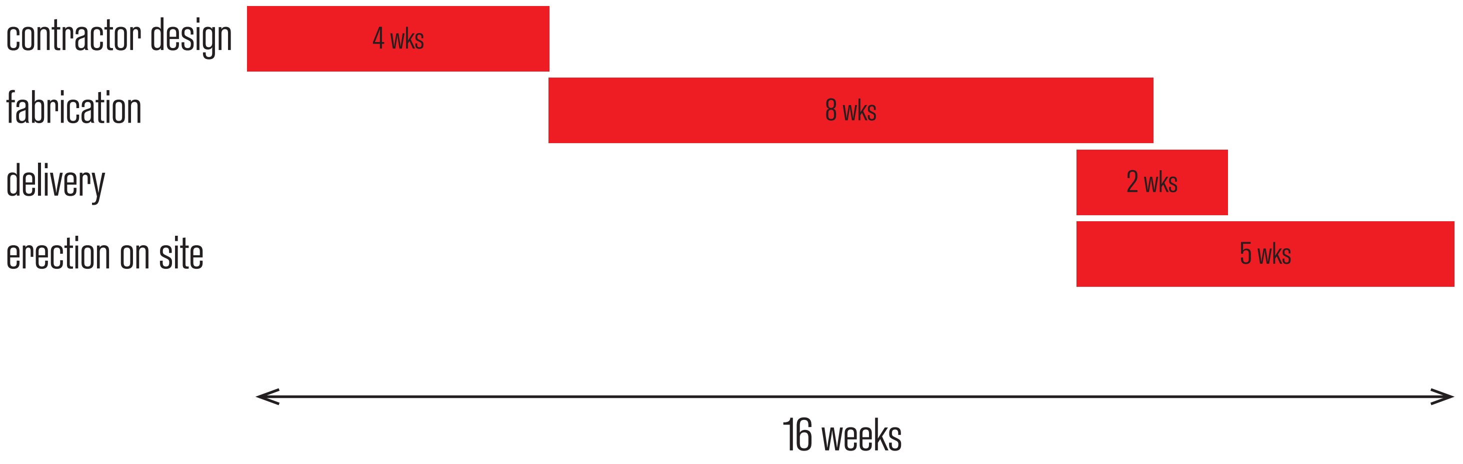
** based on December 2024 cost benchmark data provided by BCSA, AECOM and Steel for Life.

3.0 Procurement and construction

The procurement and construction comparison here is for the primary structural frame only, on the basis that the other parts of the building will be the same for a minimass frame or a steel frame. Steel and minimass are directly comparable in this sector.

3.1 Example steel construction programme

For a typical steel industrial building (greater than 10,000 sqm), the lead-in time (time from order to arrival of elements on site) is expected to be approximately 12 weeks. This would break down into a period for contractor design / detailing followed by fabrication and delivery. For erection, a typical gang of 4 people, with a crane and MEWPs would erect 1,500 sqm of steelwork per week. For the schedule below, we have assumed 2 gangs on site, working at the same time, requiring a total of 5 weeks for erection of the full 15,120 sqm.

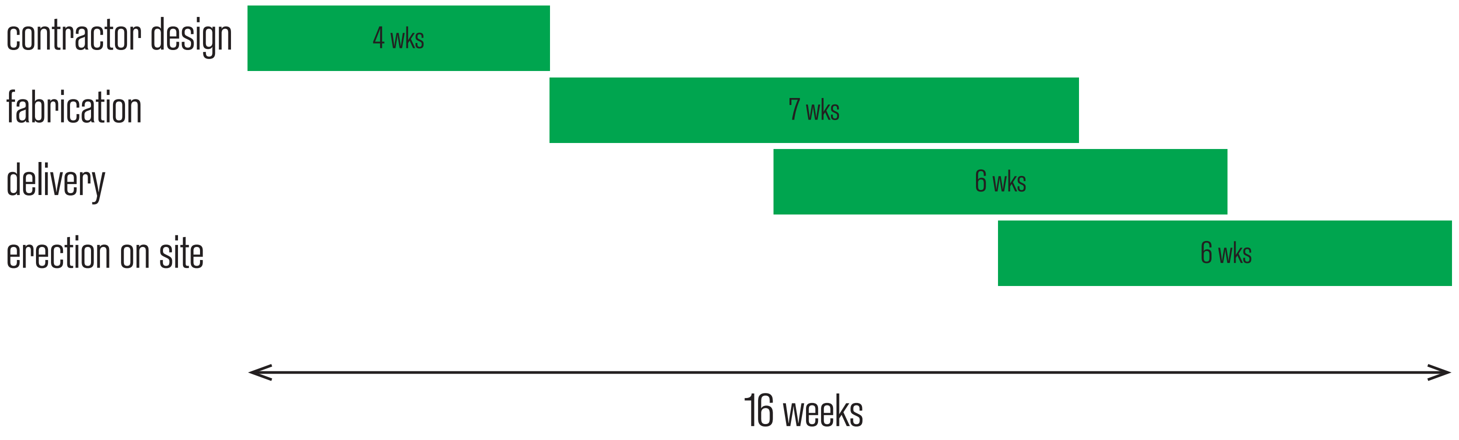


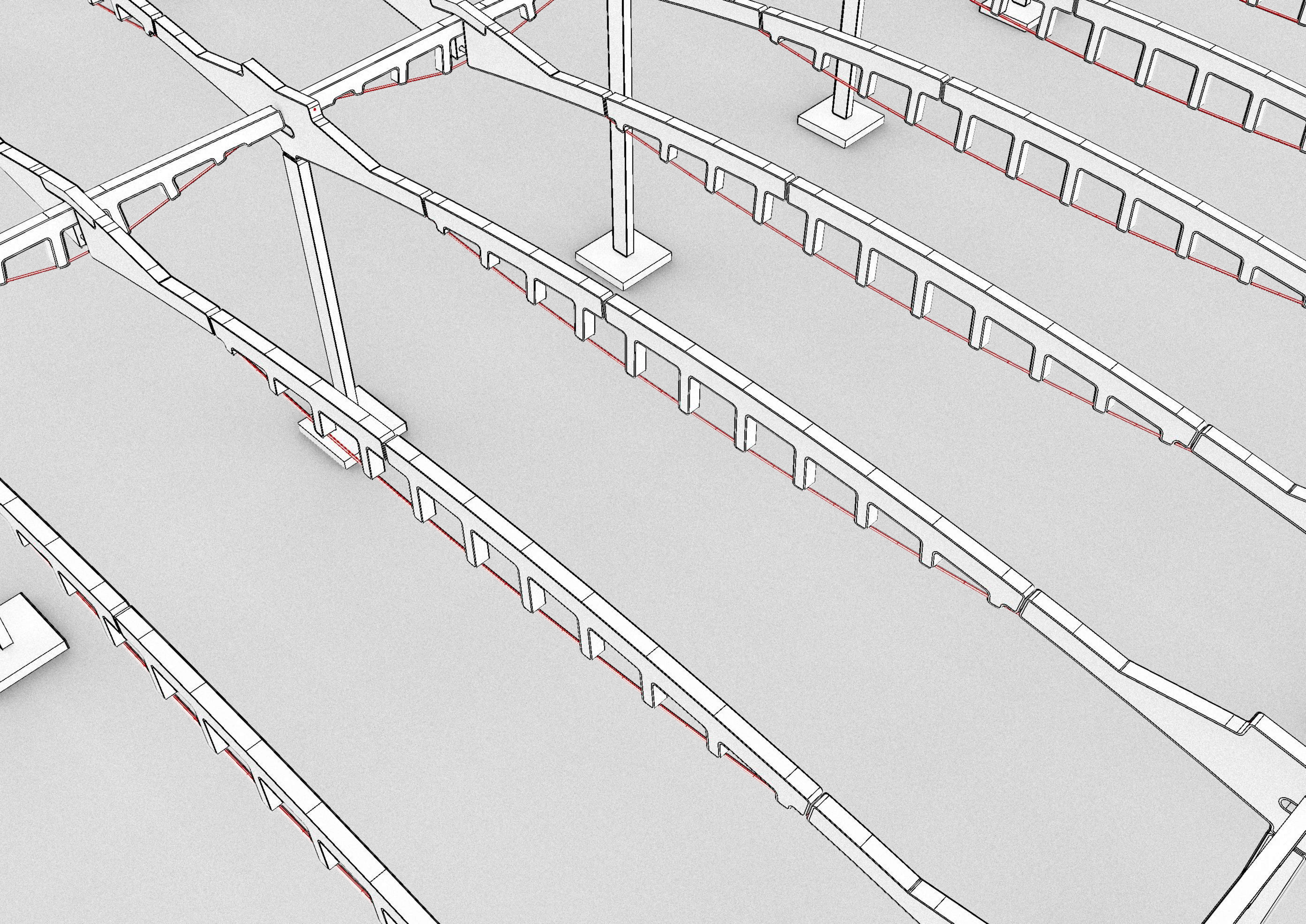
3.2 Example minimass construction programme

At full capacity, the minimass 3D printing set-up can produce 8 elements per day, each with a length of up to 15 m. However, to allow for some down-time of the equipment and to build in some robustness to the schedule, we have assumed the use of two printers, producing 6 elements per day, resulting in a production capacity of 60 elements per week. Those elements are ready to be transported to site and erected a minimum of 1 week after fabrication. An analysis of the building design shows the following breakdown in the number of concrete pieces and the indicated number of crane picks, per day at that given weight:

weight per element	no. of elements	crane picks per day
W < 10 t	295	12
10 t < W < 18.3 t	117	4

We can assume 2 gangs on site, the same as for the steelwork erection, giving us an estimated 27 days of site installation time.





4.0 Technical design

The design of any building needs an understanding of the user requirements and local market construction methods. However, this model warehouse solution aims to provide a generic "minimum viable product" for a minimass long-span warehouse, using a 4-bay portal frame approach. The following list of assumptions is considered as a baseline case, with all potential design options open for custom solutions, as the need arises on specific projects.

4.1 Size and shape

B = 15 m primary grid width

B_{sec} = 7.5 m secondary beam spacing (roof purlin span)

L = 36 m primary grid length

H = 12 m eaves height of the building (underside of the structure at the roof / column interface)

n_L = 4 no. of bays in the span direction

n_B = 7 no. of bays in the width direction (this can be increased or reduced to suit)

$\sum L$ = 144 m total building width

$\sum B$ = 105 m total building length

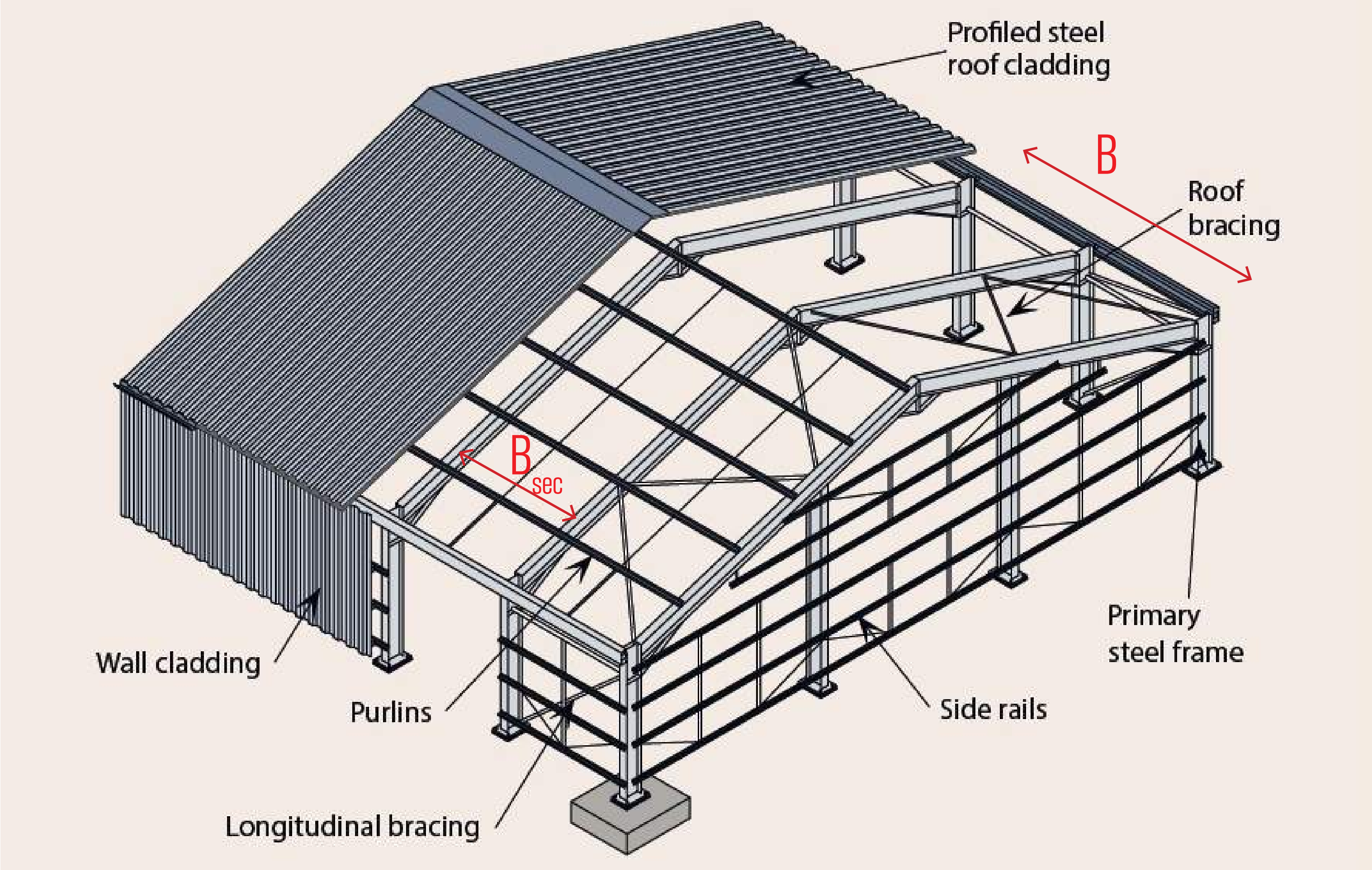
4.2 Lateral stability

In the span direction, the portal frame structure will provide the lateral stability. In the orthogonal direction to the portal frames, vertical cross bracing will be provided in the perimeter walls. However, we recognise that it is also possible - and may be preferable for certain uses - to have portalised bays in this direction as well. This is considered a viable option, if necessary.

4.3 Roof build up

There are many different options for roof structure, where local supply considerations may dominate. In this case and as a "typical" solution, the proposed roof surface is a structural metal deck that spans between cold-rolled purlins. The

Example steel frame for an industrial building.



Schematic showing typical elements of an industrial building.

purlins span between the rafter beams, with a length of 7.5 m and a spacing of 2m. This solution has been developed using Metsec 'Z' shape purlins. Thermal insulation, roof skylights and hung services are all assumed to be incorporated in this design.

Rainwater drainage is provided by setting the roof slope as 6 degrees.

4.4 Materials

3D printed concrete = f_{ck} = 40 MPa (10mm aggregate)

infill concrete = RC40/50 (10mm aggregate)

mild steel reinforcement = B500B, f_y = 500 MPa, nominal cover = 30mm (min)

PT cables = Y1860S, f_y = 1860 MPa

4.5 Permanent loads

roof deck self-weight	=	0.071 kN/m^2	Tata steel RoofDek D35, 2 m span
insulation self-weight	=	0.05 kN/m^2	estimate
roof purlins	=	0.049 kN/m^2	Metsec Z purlin 202.Z.18, 7.5 m span
services	=	0.15 kN/m^2	estimate
structure self-weight	=	as calculated	
rooftop PV panels	=	not included here but could be added as an option	

4.6 Variable loads

roof live load	=	0.60 kN/m^2	
roof snow load	=	0.40 kN/m^2	based on ground snow load of 0.5 kN/m^2
horizontal wind pressure	=	0.47 kN/m^2	(resultant) based on $v_{b,map}$ = 22 m/s
suction wind pressure	=	-0.33 kN/m^2	roof, resultant
downwards wind pressure	=	0.11 kN/m^2	at central ridge line

4.7 Foundations

Foundation design has to be site specific. However, for the purposes of comparison and carbon estimation, the foundation solution is assumed to be shallow pad footings with a top of foundation level 450 mm below grade. The ground is assumed to be moderately firm, with a bearing capacity (service level) of 200 kN/m^2.

4.8 Ground bearing slab

Industrial buildings are typically built with a ground bearing slab that is independent of the main structural frame. This approach is assumed to be taken here, with a slab between 150 mm to 250 mm thick, depending on load requirements and ground conditions. Contraction joints, joint protection and all relevant detailing would be considered as required.

4.9 Wall cladding

The external walls to the building can be made using either cold-formed steel rails and cladding, or with a precast concrete panelised system. Each option has advantages but the choice is independent of the primary structural system that is designed and described in this document.

4.10 Fire protection

Single storey industrial structures typically do not require fire protection, unless the "boundary condition" i.e. adjacent buildings require fire separation. It may be necessary to provide fire protection for a specific client due to insurance requirements but this would be treated on a case-by-case basis.

4.11 Concrete connections

Refer to section 5.0 for further details.

4.12 Construction sequence

Refer to section 6.0 for further details.

5.0 Concrete connections

Traditional concrete structures - even when using precast elements - will usually rely on "cast-in" or grouted dowel connections between pieces. The speed of these connection types is the primary drawback for concrete element construction compared to structural steel construction - which has very fast and well understood connections.

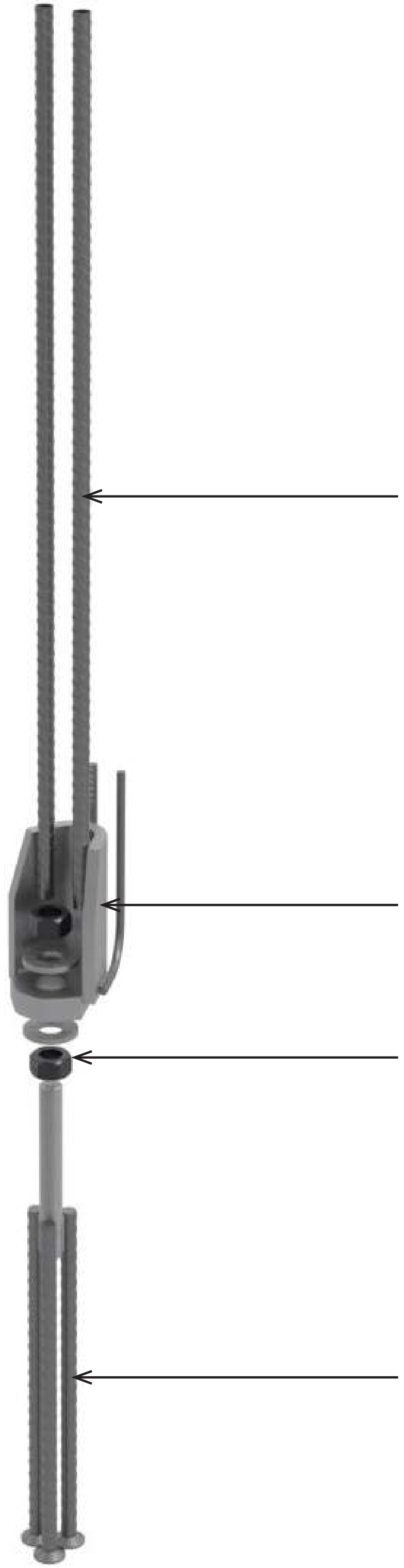
However, the minimass approach is to use bolted connections - for immediate connection strength and stiffness - but applied to concrete structures. This has become possible in recent times with the innovation in precast concrete connection technology, driven by suppliers such as Peikko. This method allows the transfer of tension, compression and shear directly across a joint using bolts which lap with reinforcement embedded on either side. Typically a gap is included between the two elements, to allow for positional tolerance, which is then grouted after the bolts are tightened. Whilst grout is still used in this case, the temporary (construction stage) loading is accommodated within the capacity of the bolts themselves, therefore the connection is strong enough immediately for erection to continue without waiting.

Bolted concrete connections are typically used in conditions where two parallel surfaces must be joined, e.g. for a column connecting to the top of a pad foundation, or for a beam connecting to the side of a column. For situations where other orientations are required, e.g. the connection of a diagonal brace member, this system does not work, without some sort of design intervention. However, this is precisely what minimass has achieved - where the steel industry has the ability to fabricate any connection geometry, minimass has the ability to design and manufacture any concrete connection geometry.

The use of these components generates a big increase in the speed of installation of concrete structures, bringing the erection time of a bolted concrete structure down to the same level as that of a traditional steel frame.

Peikko website image: concrete bolted connection during erection.

Peikko website image: concrete elements prefabricated with bolt locations.



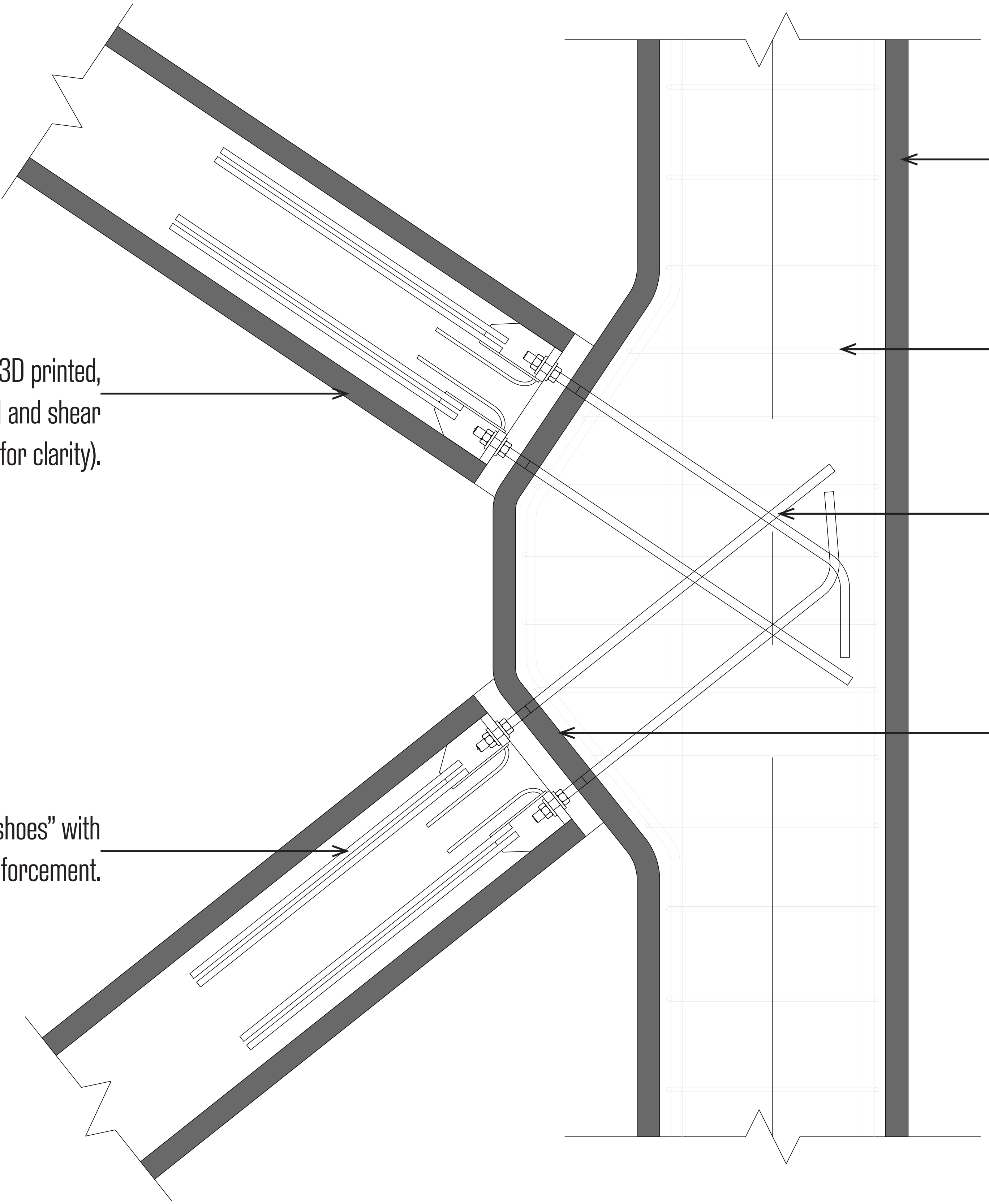
Splice reinforcing bars cast into the concrete on one side of the connection. These bars lap with the main reinforcing bars in the element.

Fabricated "shoe" to house the bolt opening.

Nuts and washers for setting the level and locking off the connection.

Splice reinforcing bars cast into the concrete on the other side of the connection. These bars either anchor into the concrete directly (e.g. pad foundation), or lap with the primary reinforcing bars in the element (e.g. column splice).

Peikko website image: components of a bolted connection.



3D printed concrete to make the bespoke shape of the element at the connection.

Longitudinal and shear reinforcement in the element receiving the connected part.

Bolts with splice reinforcement cast in to the receiving element.

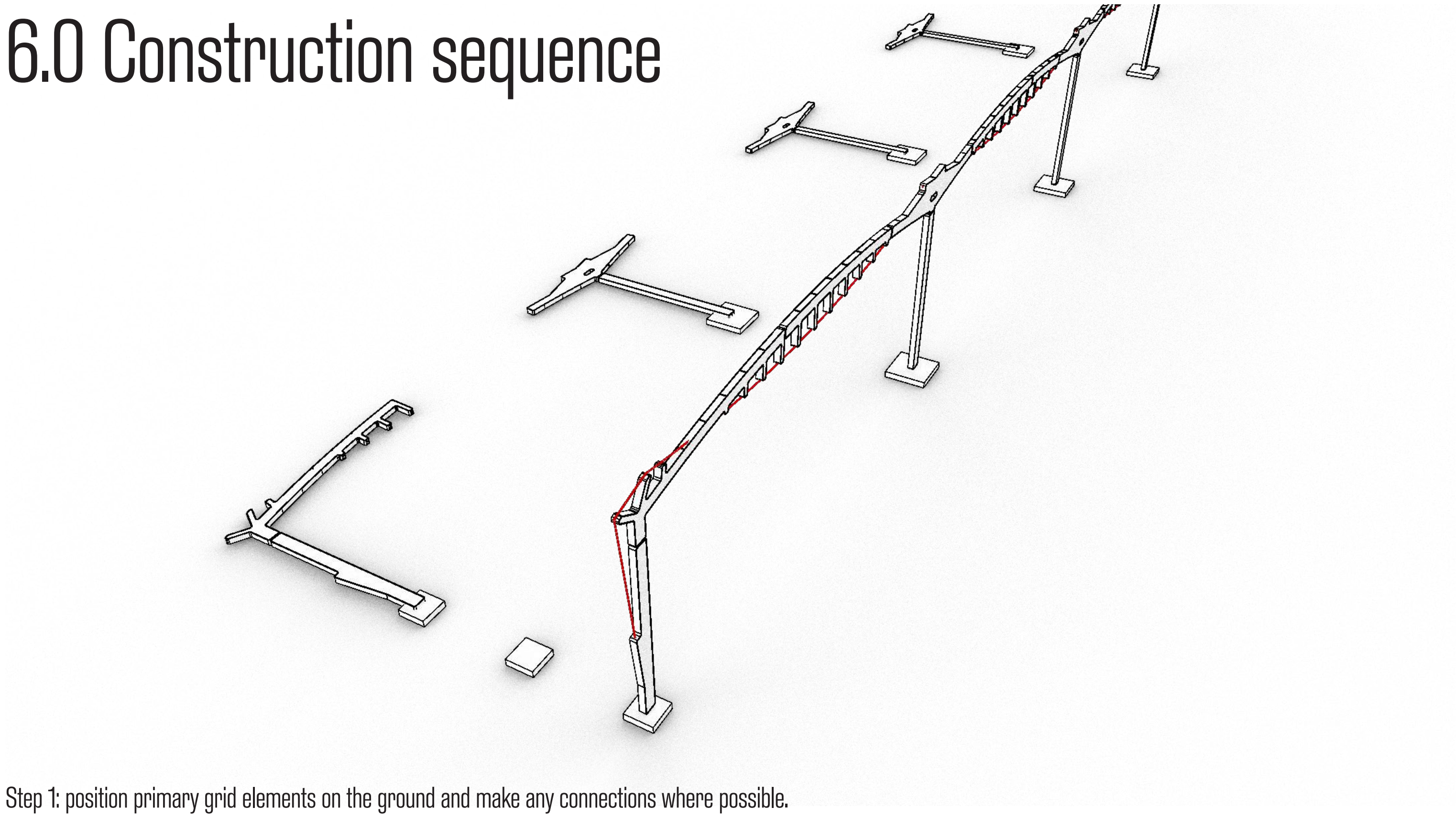
The shape of the contact surfaces can be defined to make sure the connection faces are always parallel, making the positioning and tightening of the bolts a simple task on site.

Connecting part, also made using 3D printed, reinforced concrete (longitudinal and shear reinforecment not shown, for clarity).

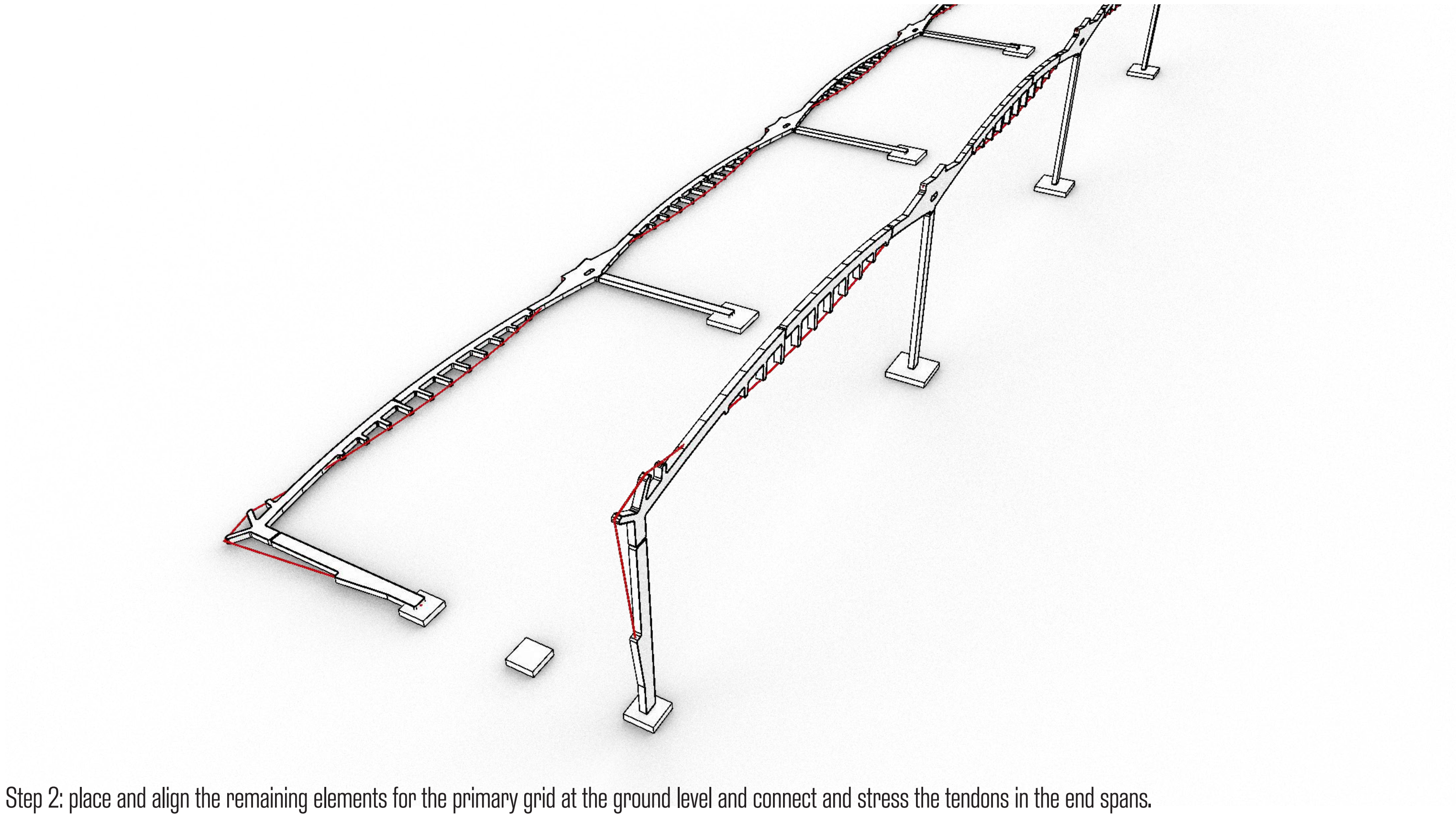
Cast in bolt “shoes” with splice reinforcement.

minimass bolted cross bracing connection, schematic design

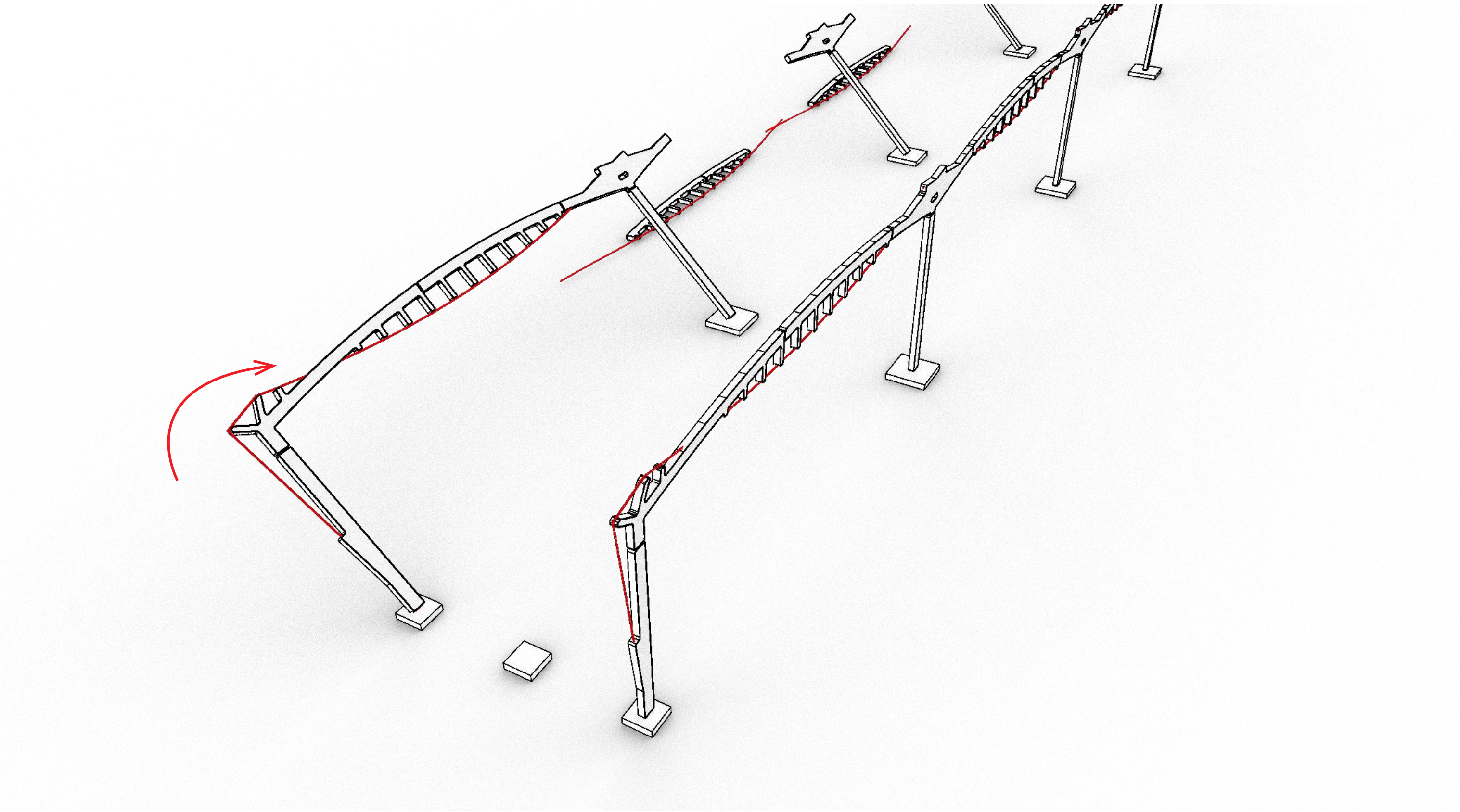
6.0 Construction sequence



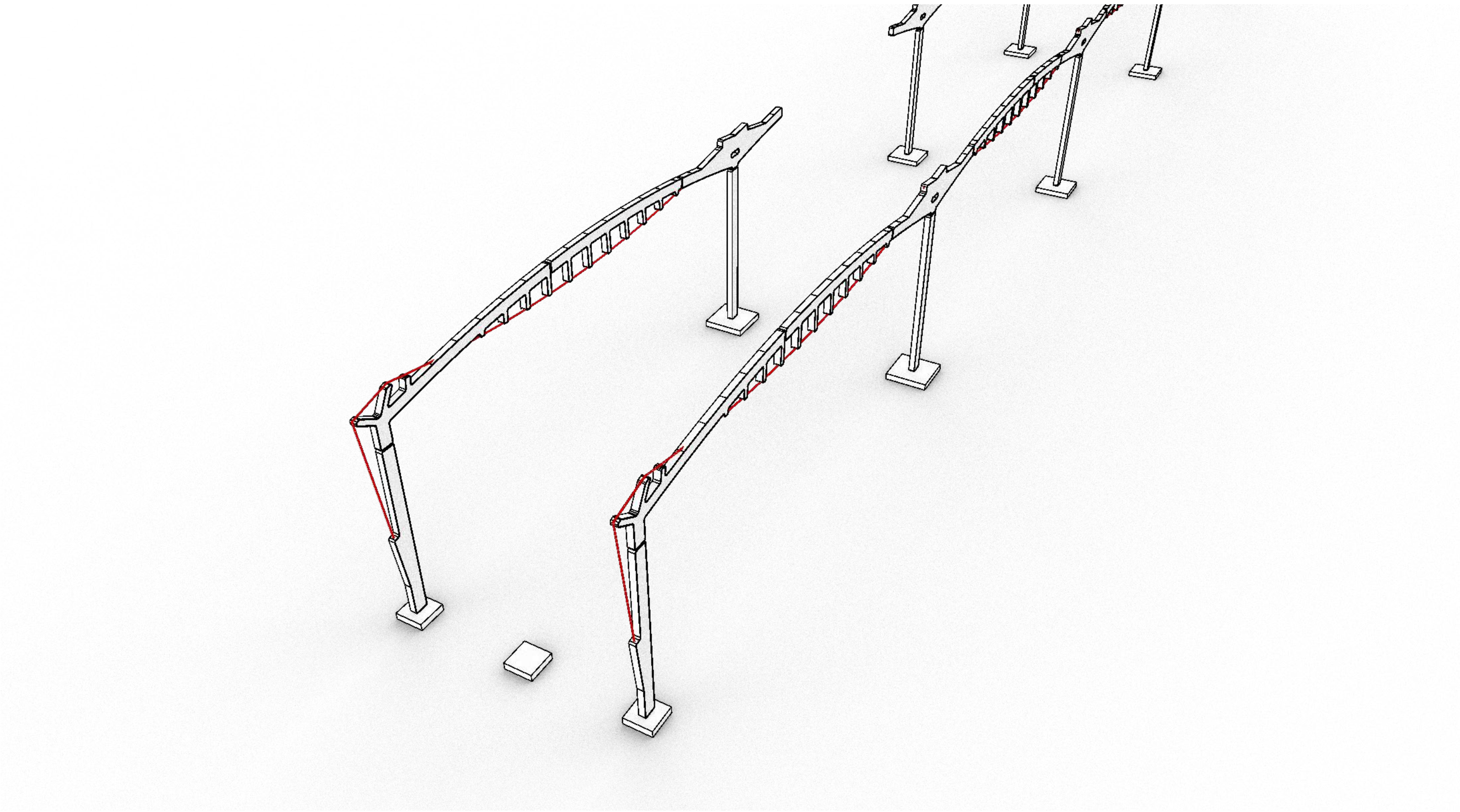
Step 1: position primary grid elements on the ground and make any connections where possible.



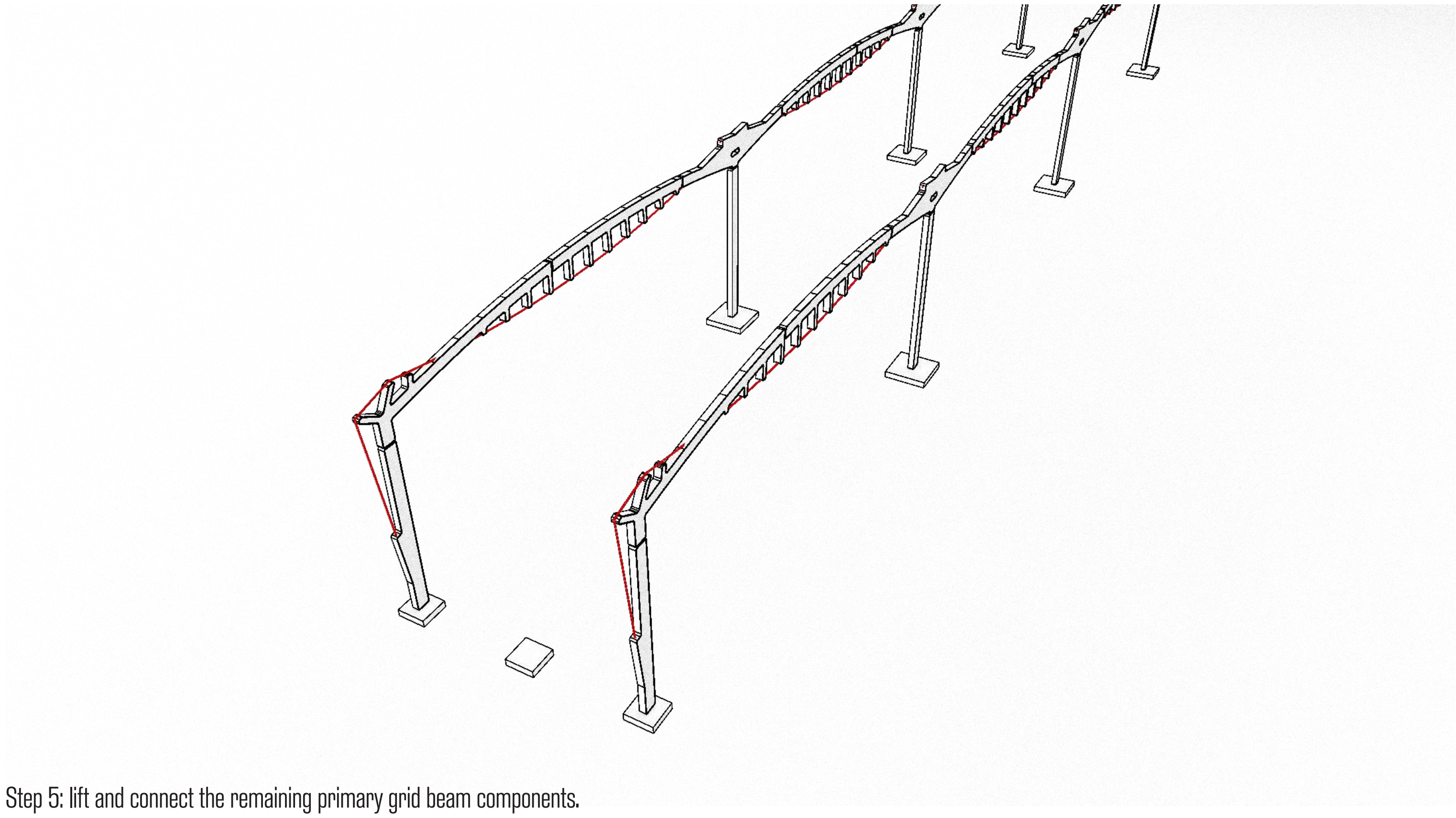
Step 2: place and align the remaining elements for the primary grid at the ground level and connect and stress the tendons in the end spans.



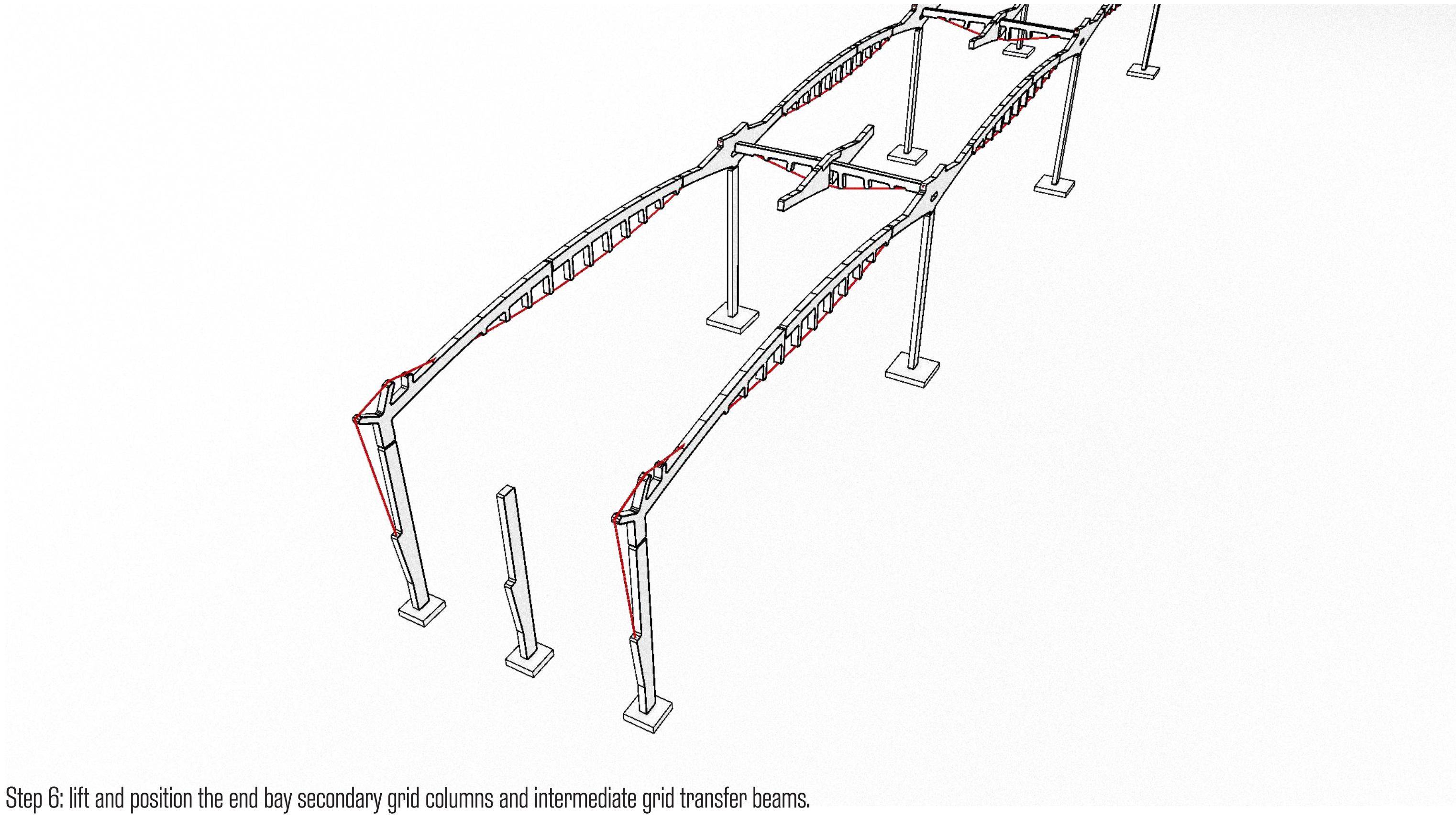
Step 3: tilt up the complete end bays and the internal columns.



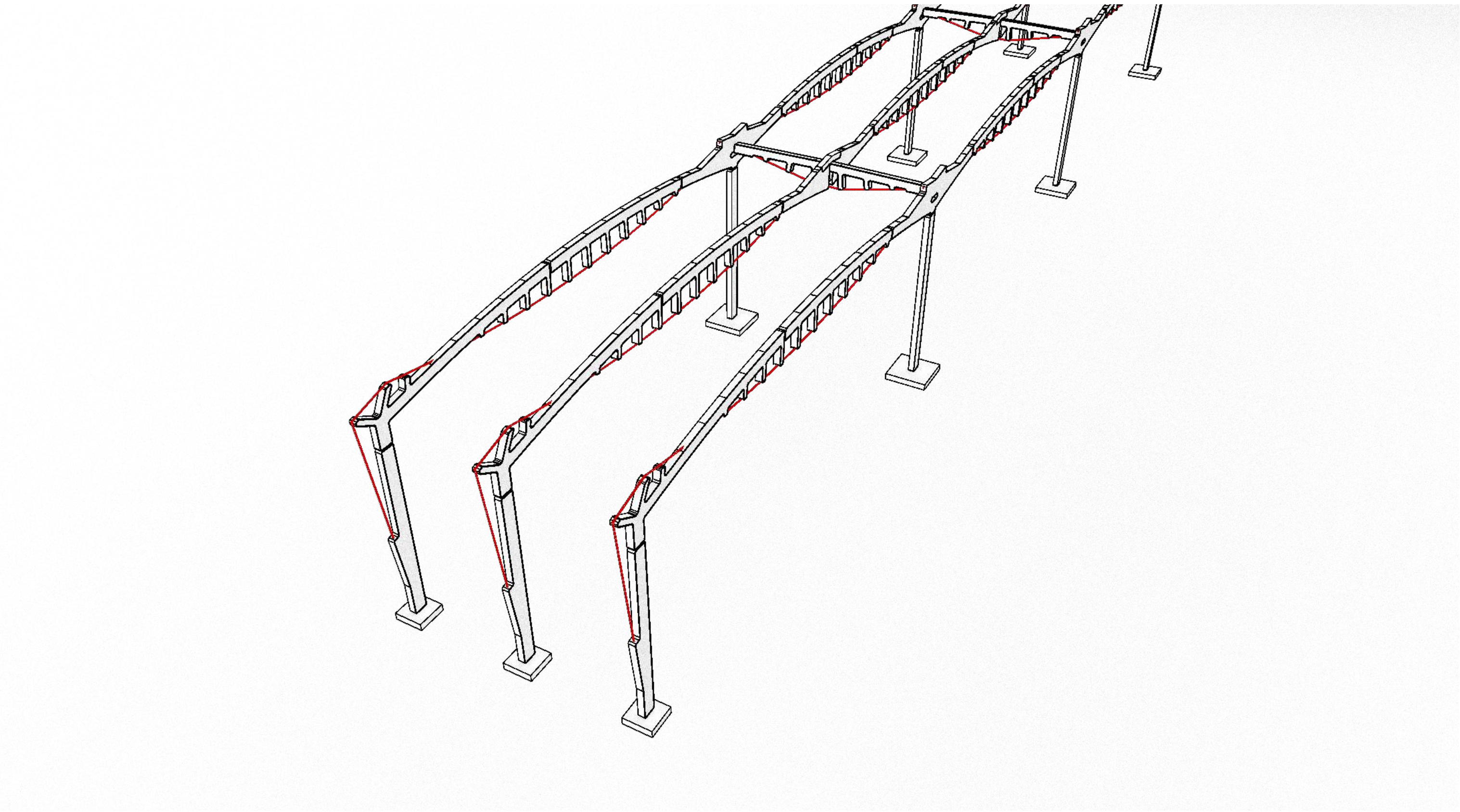
Step 4: secure elements in the vertical position.



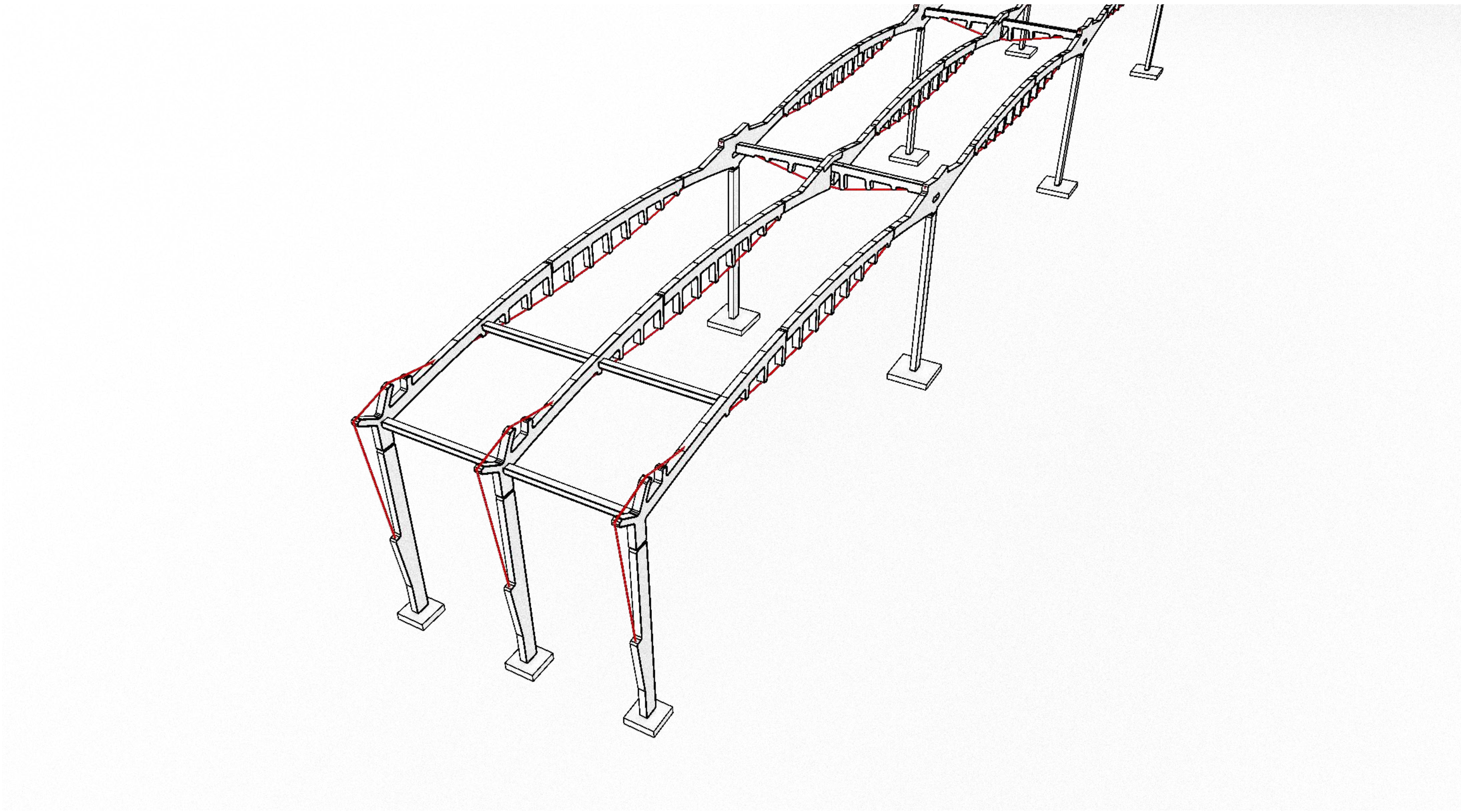
Step 5: lift and connect the remaining primary grid beam components.



Step 6: lift and position the end bay secondary grid columns and intermediate grid transfer beams.



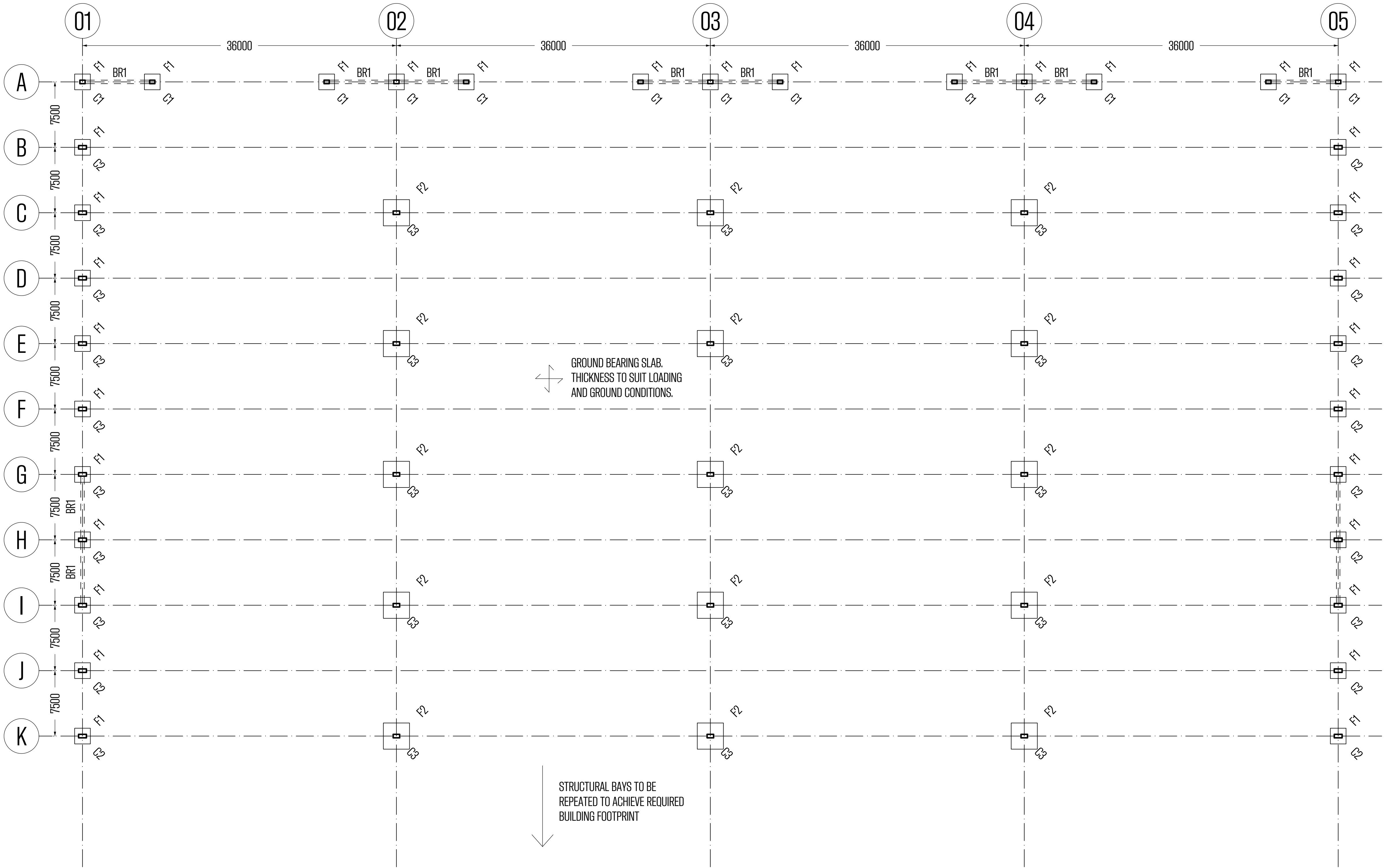
Step 7: lift and position the remaining elements of the secondary grid.



Step 8: complete the primary structure with edge beams, diagonal bracing etc. Apply the permanent loads and finishes, then stress the tendons for a final time.

7.0 Drawings

NOTES:
- Work to figured dimensions only.
- All dimensions given in mm unless noted otherwise.
- 3D printed concrete to to be fck = 40MPa.
- infill concrete to be RC 40/50.
- PT tendon to be grade Y1860S.
- Corrosion protection strategy:
    - 3D printed concrete: provide sufficient cover to the embedded reinforcement.
    - PT cables: inside the building, achieve protection level PL1 (FIB Bulletin 33): enclose the individual greased and sheathed tendons within an outer duct of HDPE. Outside the building, achieve protection level PL2 (FIB Bulletin 33) either by encasing in concrete or by filling the tendon duct with grease / wax.
- PT stressing sequence:
    - 1st stressing in the factory, 2nd stressing on site. Required force and deflection criteria indicated on the beam table.
- Design loads:
    - element self-weight, as calculated
    - applied roof dead load = 0.15 kN/m^2
    - roof superimposed dead load = 0.125 kN/m^2
    - roof live load = 0.6 kN/m^2
    - roof snow load = to suit the location
    - building wind loads = to suit the location



GROUND BEARING SLAB. THICKNESS TO SUIT LOADING AND GROUND CONDITIONS.

STRUCTURAL BAYS TO BE REPEATED TO ACHIEVE REQUIRED BUILDING FOOTPRINT

GENERAL ARRANGEMENT: GROUND FLOOR

PAD FOUNDATION SIZES

	WIDTH (mm)	BREADTH (mm)	DEPTH (mm)	REINFORCEMENT
F1	1800	1800	450	B12 @ 150, BOTH DIRECTIONS
F2	3000	3000	450	B20 @ 180 B1, B20 @ 150 B2

STRUCTURAL ELEMENT SIZES

	WIDTH (mm)	BREADTH (mm)	REINFORCEMENT
C1	400	600	8 NO. B16, B10 LINKS @ 250
C2	400	900	12 NO. B32 (ROOF), 12 NO. B20 (BASE), B10 LINKS @ 250
C3	400	750	12 NO. B20, B10 LINKS @ 250
BR1	400	400	8 NO. B25, B10 LINKS @ 250

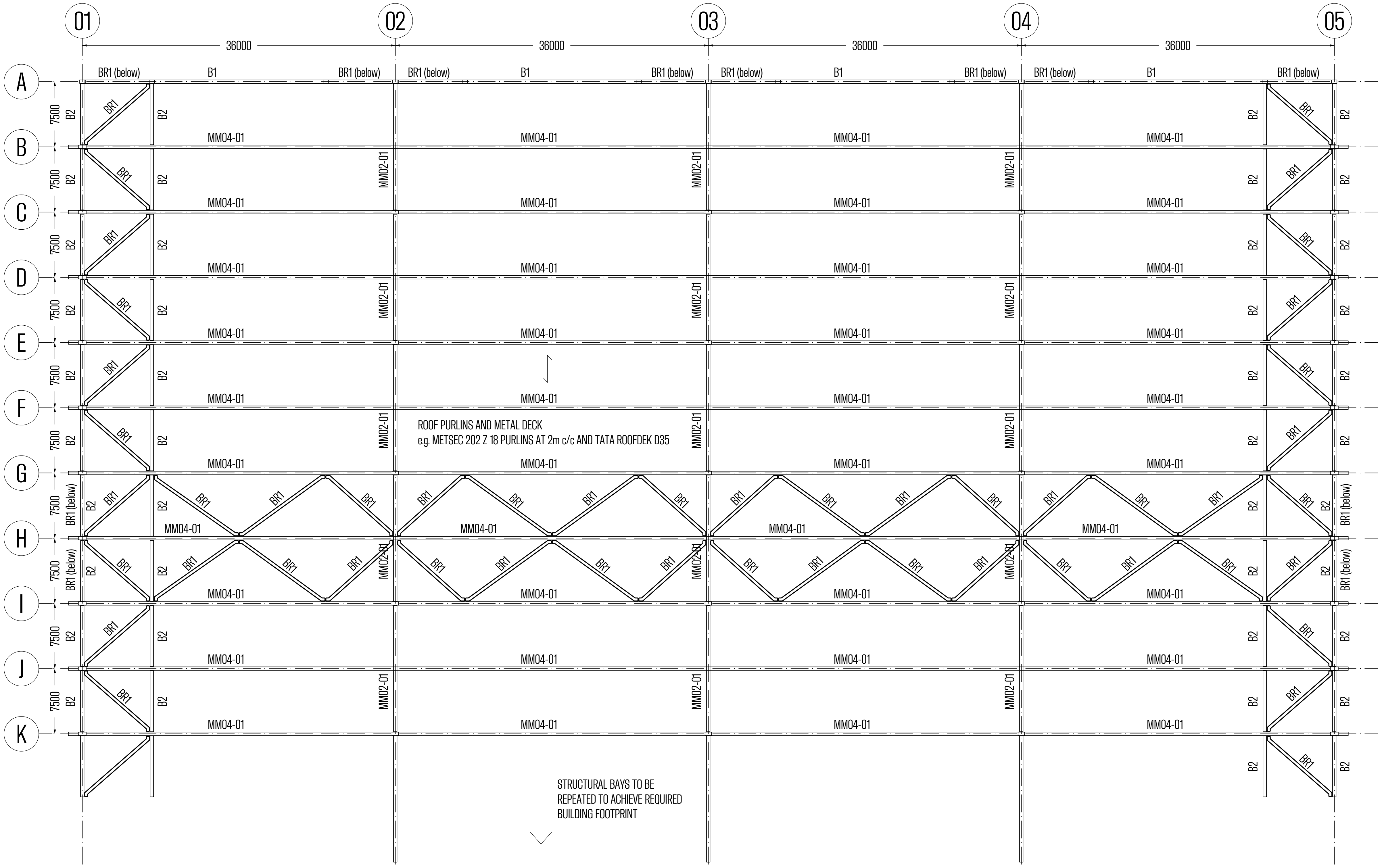
NOT FOR CONSTRUCTION

minimass™

MINIMASS WAREHOUSE
GA: GROUND FLOOR

DATE:	21/01/2025
BY:	ARC
SCALE:	1:500 @ A3
DRAWING:	S001
REVISION:	00

NOTES:
- Work to figured dimensions only.
- All dimensions given in mm unless noted otherwise.
- 3D printed concrete to to be fck = 40MPa.
- infill concrete to be RC 40/50.
- PT tendon to be grade Y1860S.
- Corrosion protection strategy:
  - 3D printed concrete: provide sufficient cover to the embedded reinforcement.
  - PT cables: inside the building, achieve protection level PL1 (FIB Bulletin 33): enclose the individual greased and sheathed tendons within an outer duct of HDPE. Outside the building, achieve protection level PL2 (FIB Bulletin 33) either by encasing in concrete or by filling the tendon duct with grease / wax.
- PT stressing sequence:
  - 1st stressing in the factory, 2nd stressing on site.
- Design loads:
  - element self-weight, as calculated
  - applied roof dead load = 0.15 kN/m^2
  - roof superimposed dead load = 0.125 kN/m^2
  - roof live load = 0.6 kN/m^2
  - roof snow load = to suit the location
  - building wind loads = to suit the location



ROOF PURLINS AND METAL DECK
e.g. METSEC 202 Z 18 PURLINS AT 2m c/c AND TATA ROOFDEK D35

STRUCTURAL BAYS TO BE REPEATED TO ACHIEVE REQUIRED BUILDING FOOTPRINT

GENERAL ARRANGEMENT: ROOF

STRUCTURAL ELEMENT SIZES

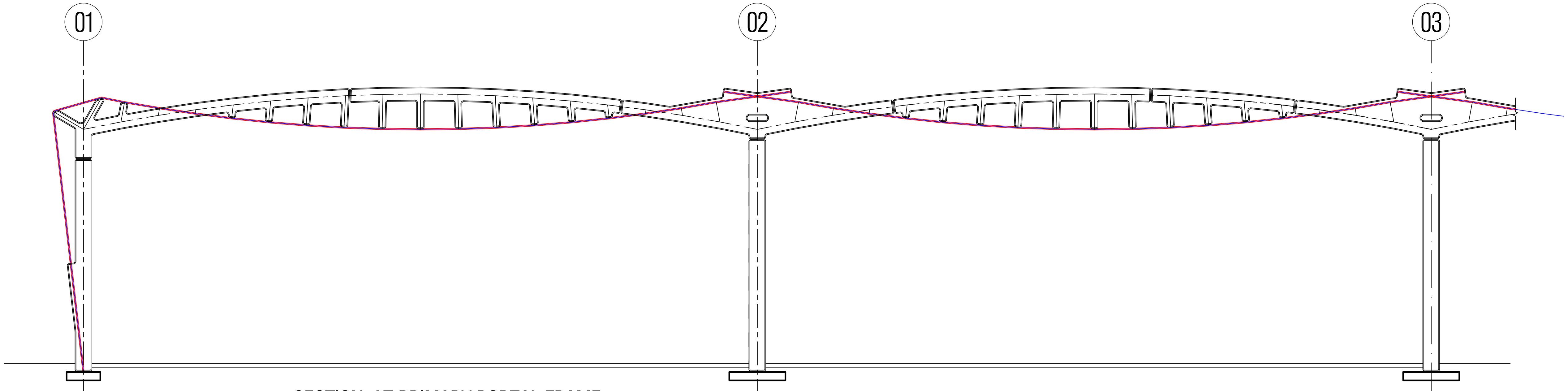
	WIDTH (mm)	DEPTH (mm)	REINFORCEMENT	POST-TENSIONING
MM02-01	400	600	4 B25 (T), 3 B20 (B), B8 LINKS @ 250	13 NO. 15.7 DIA. STRANDS
MM04-01	400	750	4 B20 (T), 4 B20 (B), B10 LINKS @ 350	5 NO. 15.7 DIA. STRANDS
B1	400	750	8 NO. B25, B10 LINKS @ 300	-
B2	400	400	8 NO. B25, B10 LINKS @ 250	-
BR1	400	400	8 NO. B25, B10 LINKS @ 250	-

NOT FOR
CONSTRUCTION

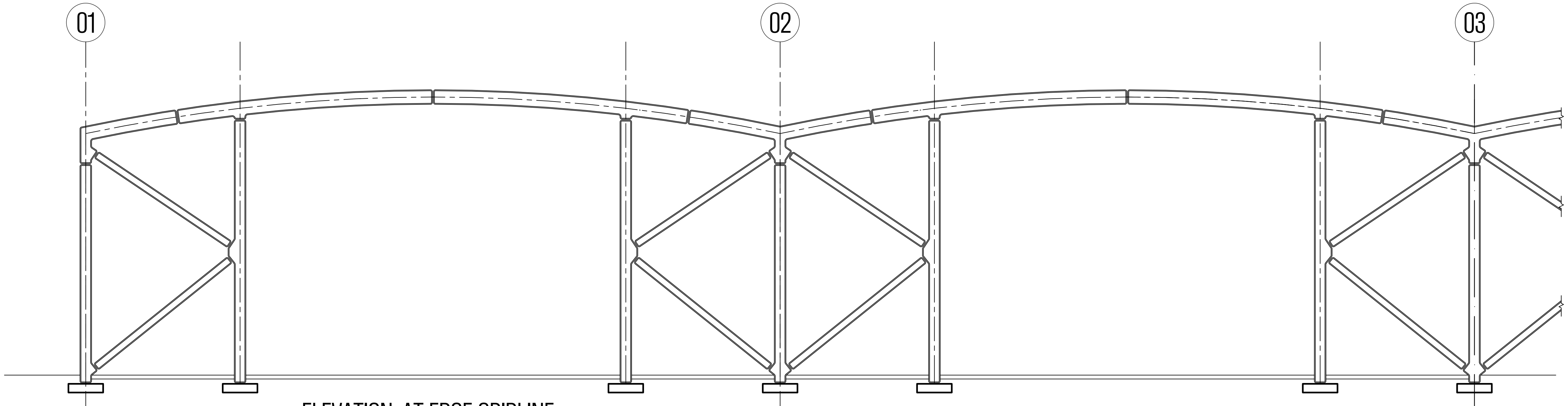
minimass™

MINIMASS WAREHOUSE
GA: ROOF

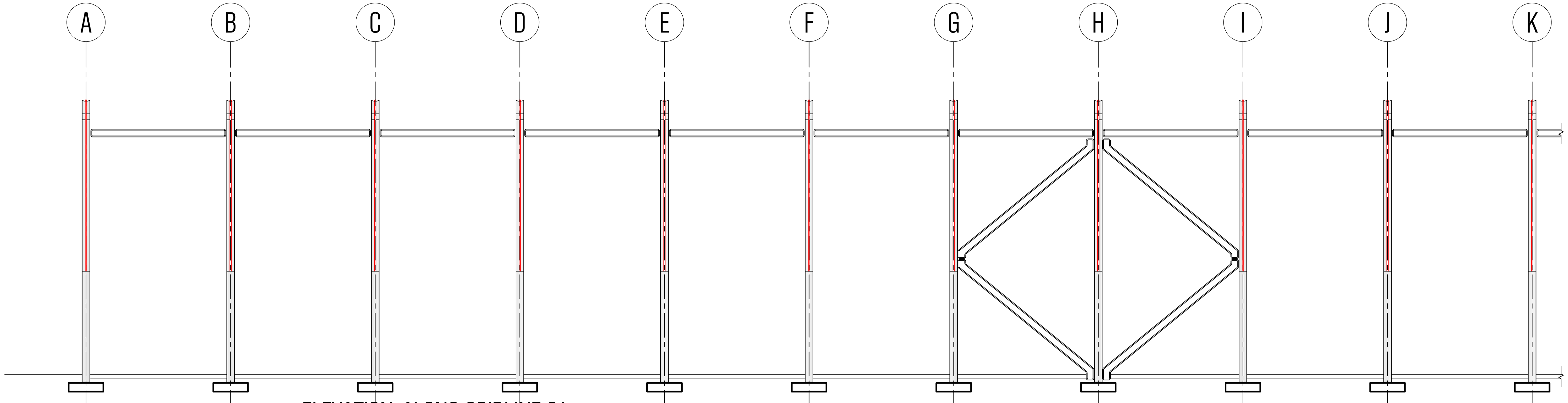
DATE:	21/01/2025
BY:	ARC
SCALE:	1:500 @ A3
DRAWING:	S002
REVISION:	00



SECTION: AT PRIMARY PORTAL FRAME



ELEVATION: AT EDGE GRIDLINE



ELEVATION: ALONG GRIDLINE 01

NOTES:
- Work to figured dimensions only.
- All dimensions given in mm unless noted otherwise.
- 3D printed concrete to to be fck = 40MPa.
- infill concrete to be RC 40/50.
- PT tendon to be grade Y1860S.
- Corrosion protection strategy:
  - 3D printed concrete: provide sufficient cover to the embedded reinforcement.
  - PT cables: inside the building, achieve protection level PL1 (FIB Bulletin 33): enclose the individual greased and sheathed tendons within an outer duct of HDPE. Outside the building, achieve protection level PL2 (FIB Bulletin 33) either by encasing in concrete or by filling the tendon duct with grease / wax.
- PT stressing sequence:
  - 1st stressing in the factory, 2nd stressing on site.
- Design loads:
  - element self-weight, as calculated
  - applied roof dead load = 0.15 kN/m^2
  - roof superimposed dead load = 0.125 kN/m^2
  - roof live load = 0.6 kN/m^2
  - roof snow load = to suit the location
  - building wind loads = to suit the location

NOT FOR
CONSTRUCTION

minimass™

MINIMASS WAREHOUSE
ELEVATIONS & SECTIONS
DATE: 21/01/2025
BY: ARC
SCALE: 1:250 @ A3
DRAWING: S003
REVISION: 00

APPENDIX

A1: Detailed calculations for the minimass structure

element	beams				columns				diagonal bracing	
	main portal frame	edge beams	edge beams	transfer beams	internal	edge, portal frame	edge, braced	corner	vertical	horizontal
grids	B to N	A & O	1 & 5	2, 3 & 4	2/C to 4/M	1 & 5	A & O	A/1 etc.	-	.
number of	52	8	28	21	18	26	22	4	40	84
length (m)	36	36	7.5	15	12.95	12.95	12.95	12.95	10	11
type	mm-04	3DPRC	3DPRC	mm-02	3DPRC	3DPRC	3DPRC	3DPRC	3DPRC	3DPRC
width (mm)	400	400	400	400	400	400	400	400	400	400
depth (mm)	750	750	400	600	750	900	600	600	400	400
mass										
3DCP (kg)	4750	3785	695	1755	1255	1170	1245	1135	875	1000
infill concrete (kg)	30815	23300	1985	8770	7840	9335	6090	5460	2500	2915
rebar (kg)	1115	1445	300	540	515	870	250	250	400	430
PT (kg)	235	-	-	240	-	-	-	-	-	-
CO2e (per element)	values provided are lifecycle stages A1 - A5w									
3DCP (kg)	680	541	99	251	179	167	178	162	125	143
infill concrete (kg)	4684	3542	302	1333	1192	1419	926	830	380	443
rebar (kg)	932	1206	250	453	429	726	209	209	336	359
PT (kg)	195	-	-	199	-	-	-	-	-	-
CO2e (sum) (kg)	6491	5289	652	2236	1800	2312	1312	1201	841	945
CO2e (all of type) (t)	339.7	42.6	18.4	46.9	32.6	60.4	29.1	4.8	34.0	53.4
CO2e (kg/sqm)	22.3	2.8	1.2	3.1	2.1	4.0	1.9	0.3	2.2	4.7
supply cost of elements (not including cost of connections or erection)										
unit cost (£/m)	350	260	280	395	280	350	240	240	230	205
cost (all of type) (£)	655,200	74,880	58,800	124,425	65,270	117,850	68,380	12,430	94,760	189,420
Cost (£/sqm)	43.3	5.0	3.9	8.2	4.3	7.8	4.5	0.8	6.3	12.5

The total minimass supply cost = £97 /sqm but then we recommend an allowance of £5 / sqm for bolted connection components and £20 / sqm for erection, to give a total cost of £122 / sqm.

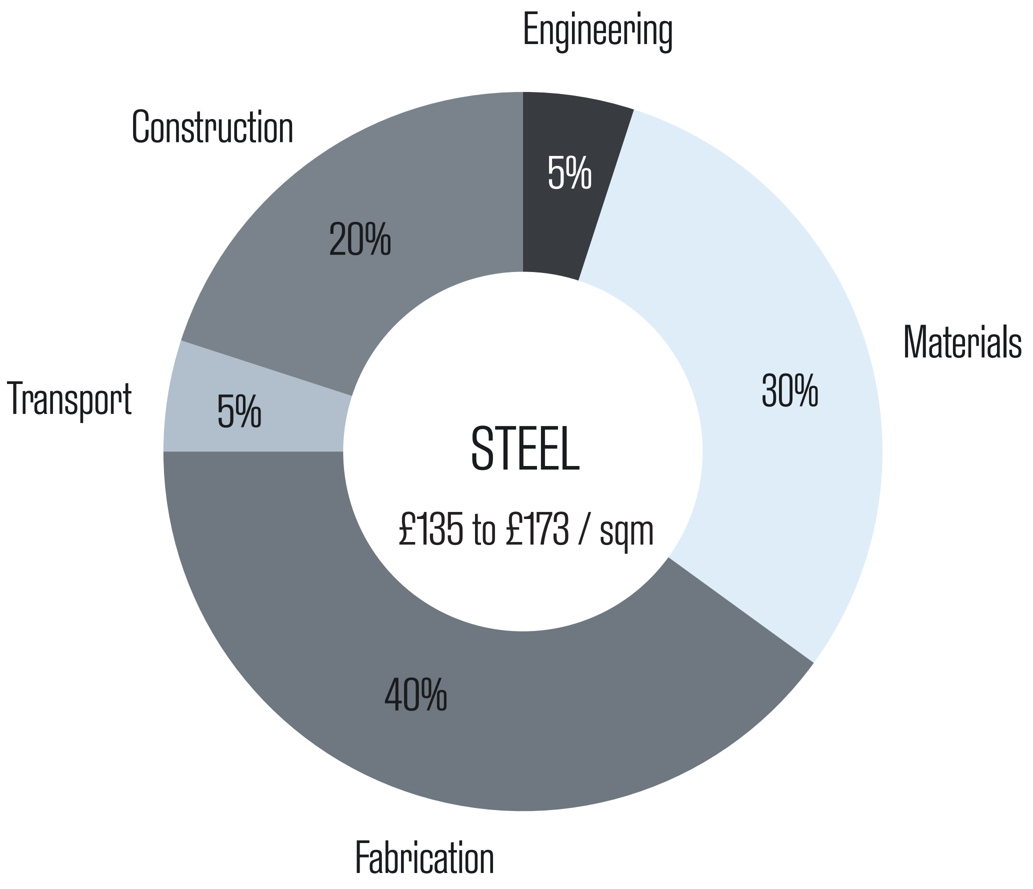
A2: Cost assumptions

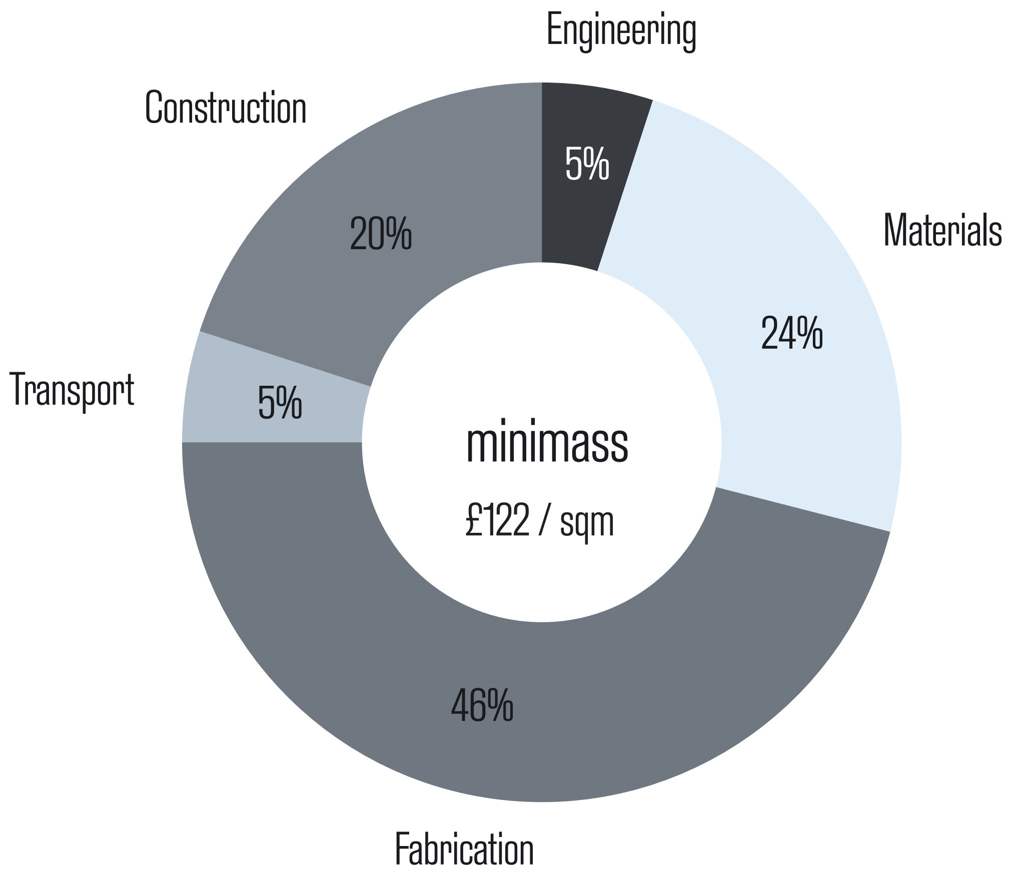
Supply cost figures are given in the table in appendix section A1. These are concept level estimates, based on the information outlined in this document.

In addition to the supply (including delivery) cost figures given in the table, an extra allowance of 5% has been made for the cost of bolted connection components and 20% for the cost of erection.

All costs should be reviewed on a project-by-project basis, with a full cost estimate completed at the time of design and development.

The charts below show a very similar breakdown in % cost components, with a marginally higher ratio of fabrication to raw materials cost for minimass, as would be expected for the 3D printing with the low cost of concrete and rebar.





A3: Carbon assumptions

Embodied carbon calculations are based on the methodology outlined in the document, “How to calculate embodied carbon”, 2nd edition, published by the Institution of Structural Engineers. Unlike the calculations for complete structures or buildings, the comparison here is well defined and simple to assess. For each beam type, the mass of concrete, reinforcement, steel and timber has been estimated, then multiplied by the appropriate weighting factor.

The weighting factors that have been used are as follows, with all units given as kg CO2e / kg of material:

stage	A1 - A3	A1 - A5w	A - C	D	sequestration	notes
poured concrete	0.138	0.152	0.170	0	0	IStructE Carbon tool v2, UK C40/50 (25% GGBS)
printed concrete	0.129	0.143	0.161	0	0	Constructionarium bridge project mix design, with embodied carbon estimated based on constituent materials, with data from ICE database v3.0. C30/37, 360 kg/m^3 CEM II/A-L, 130 kg/m^3 limestone fines, admixtures.
reinforcement	0.760	0.835	0.853	0.351	0	IStructE carbon tool v2, UK 97% recycled EAF production
PT strand	0.760	0.835	0.853	0.351	0	IStructE carbon tool v2, UK 97% recycled EAF production
mild steel	1.740	1.790	1.808	-0.920	0	IStructE carbon tool v2, UK open rolled steel sections

A4: Reference values for the base case steel portal frame

Large industrial buildings are a well-researched typology in the UK, with quarterly cost data published online. This study draws upon the resources provided by the website "www.steelconstruction.info", which describes itself as the "free encyclopedia for UK steel construction". This resource is actively maintained and developed by the British Constructional Steelwork Association (BCSA), Steel for Life and the Steel Construction Institute (SCI).

The adjacent image is an extract from the document titled, "Costing Steelwork #30, December 2024", published by BCSA, Steel for Life and AECOM.

The highlighted box refers to the comparison values for the building type and size that is described in this document. Fire protection is assumed not to be necessary and no amendment is made to the cost for allowance of location in UK, as this is purely a case study.

Whilst not explicitly stated in the document, it is assumed that the cost figures include all superstructure primary steelwork, but do not include foundations or ground floor slab. Also, it is assumed that this is the cost including erection on site.

TYPE	Base index 100 (£/m^2)	Notes
Frames		
Steel frame to low-rise building	153-186	Steelwork design based on 55kg/m^2
Steel frame to high-rise building	257-290	Steelwork design based on 90kg/m^2
Complex steel frame	290-343	Steelwork design based on 110kg/m^2
Floors		
Composite floors, metal decking and lightweight concrete topping	88-137	Two-way spanning deck, typical 3m span with concrete topping up to 150mm
Precast concrete composite floor with concrete topping	134-188	Hollowcore precast concrete planks with structural concrete topping spanning between primary steel beams
Fire protection		
Fire protection to steel columns and beams (60 minutes resistance)	24-36	Factory applied intumescent coating
Fire protection to steel columns and beams (90 minutes resistance)	30-49	Factory applied intumescent coating
Portal frames		
Large-span single-storey building with low eaves (6-8m)	111-146	Steelwork design based on 35kg/m^2
Large-span single-storey building with high eaves (10-13m)	135-173	Steelwork design based on 45kg/m^2

Figure 4: BCIS location factors, as at Q4 2024

Location	BCIS Index	Location	BCIS Index
Central London	125	Nottingham	101
Manchester	103	Glasgow	93
Birmingham	98	Newcastle	89
Liverpool	98	Cardiff	103
Leeds	90	Dublin	90*

*Aecom index

minimass™