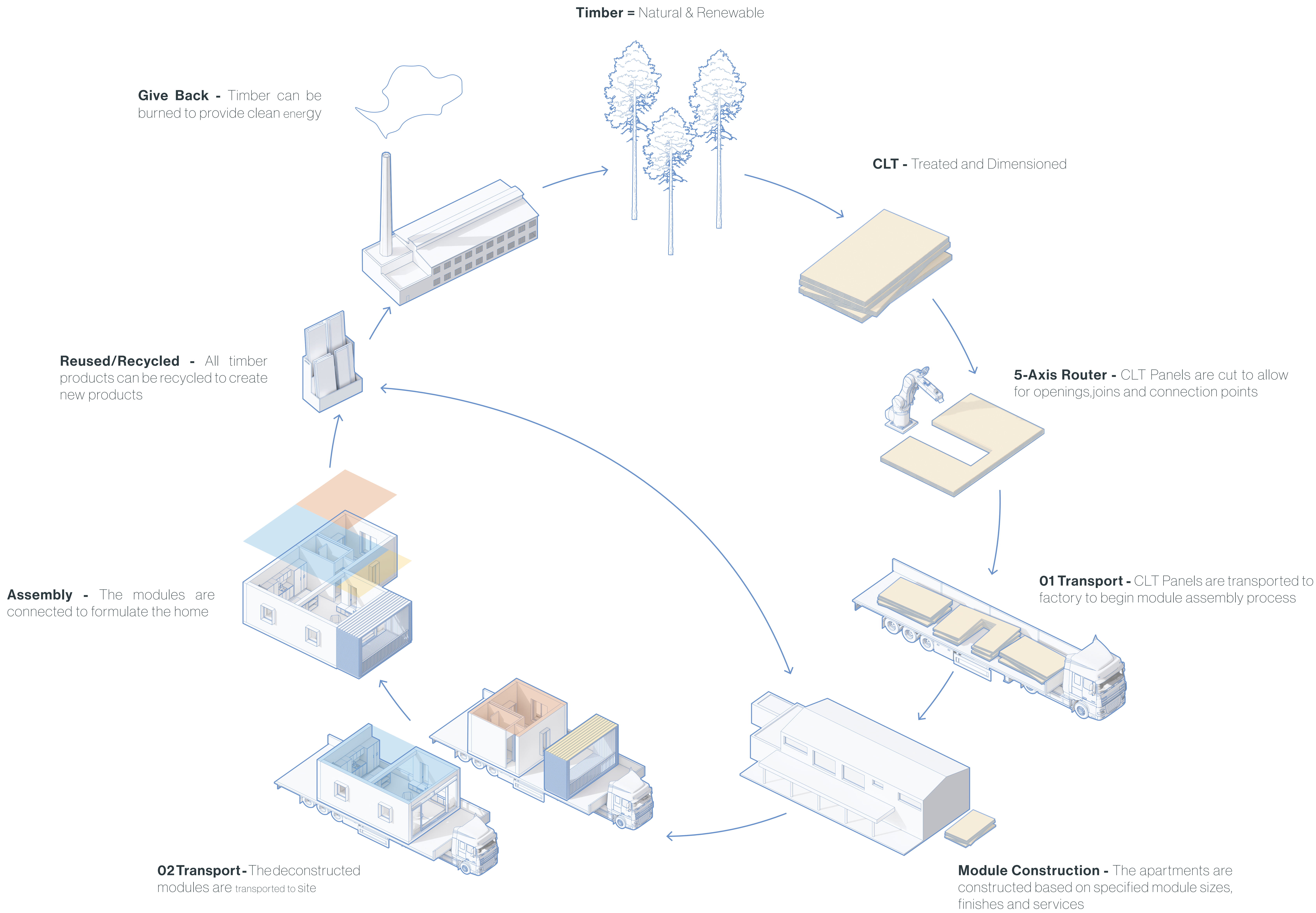
3x3haus

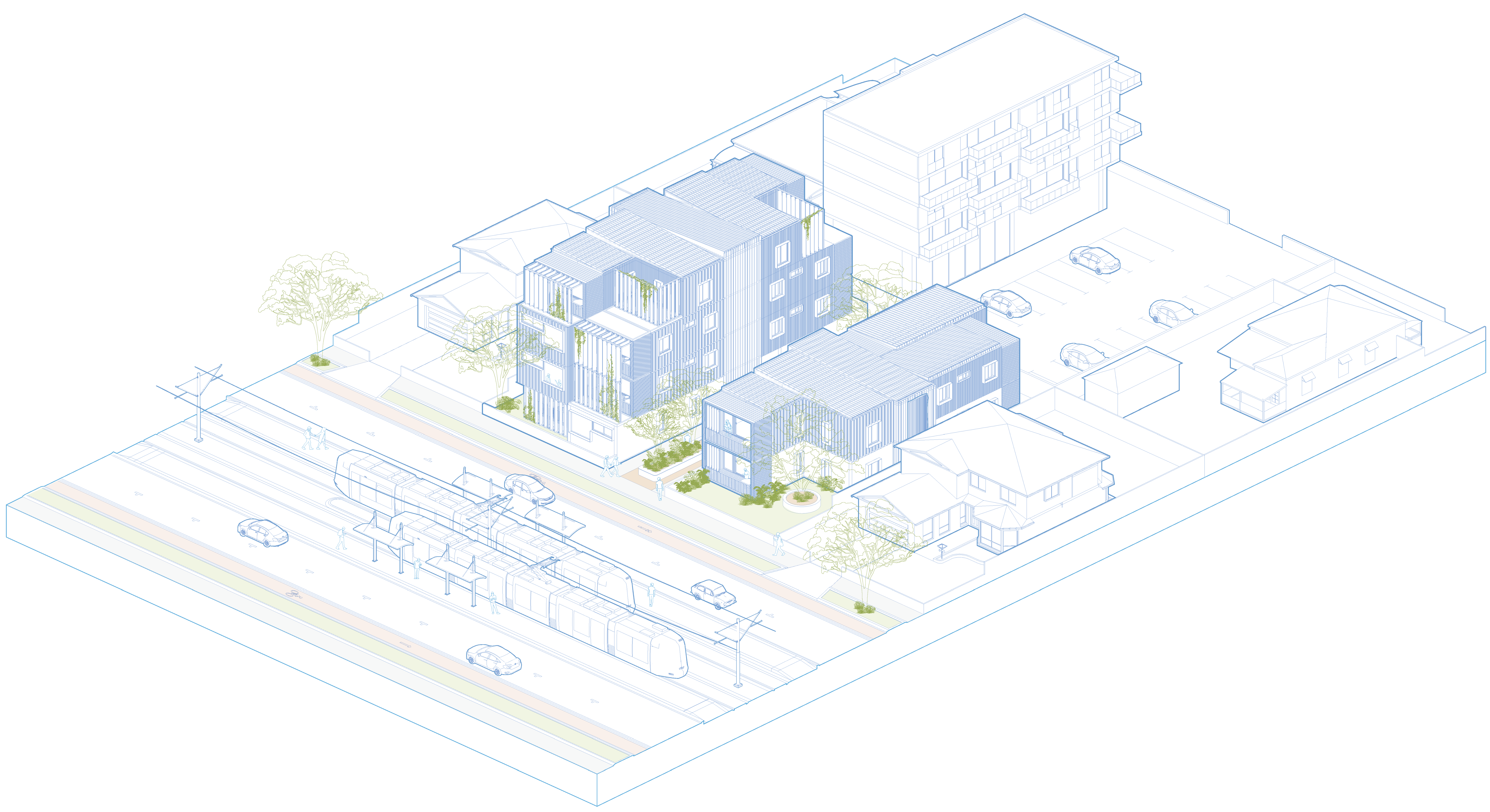
Project Intent

This project aims to challenge common misconceptions around prefabricated modular housing being a method that forces us compromise in quality of living space and architectural expression. The conceptual framework of the project is defined by every apartment being cataloged into the most fundamental aspects of living with: kitchen & living, bedroom & bathroom and balcony, all being treated as individually designed components that come together to form a complete home module. This design approach created unique opportunities for the apartment modules to be adaptable to various scales, internal functions, create new spatial planning layouts and ease for transportation and implementation into the site.



Cyclical Sustainable

The project brings a clear focus to the benefits of prefabrication in architectural design to develop healthy, comfortable carbon positive housing to Australia. Replacing the conventions of concrete and steel construction as these methods are responsible to largest amount of carbon dioxide to the atmosphere. Utilizing CLT as the primary superstructure for the apartment modules has multiple environmental benefits through its storage of CO2 in its cellular structure, as well as its flexibility in the fabrication process, especially through the implementation of robotics and CNC CAD technologies.



Welcome Home

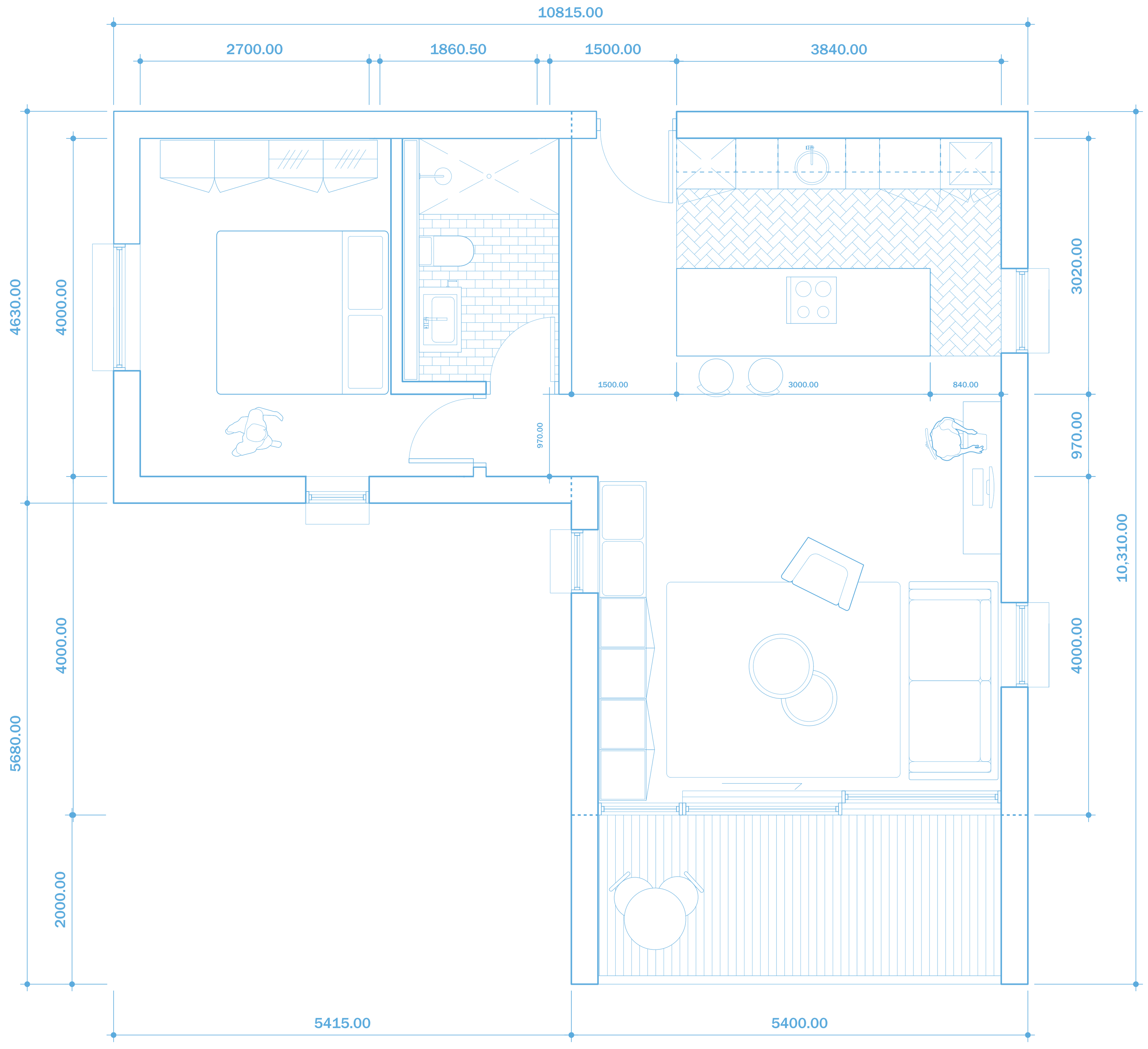
The mixed scale residential complex comprising of 4 storey's to the south of the site and 2 storey's to the north invites ample natural sunlight into the central thoroughfare laneway that provides privacy between the 2 apartment blocks through lush vegetation creates a welcoming entryway for residents when coming home. Both apartment blocks have centralised stair & lift cores which connect comfortably to the front doors of the apartment modules that are mirrored on either side of this element. A simple material palette of natural and robust local materials we used, to reflect the subtleties of the sites surrounding vernacular through the application of native hardwoods and local masonry. The materials are punctuated with crevices of mature trees and plentiful greenery, results in a building which is reflective of its context and surroundings, providing a soft impact on the streetscape and neighboring frontages.

E-04 West Elevation 1:200

1 2 3 4 10

E-02 South Elevation 1:200

1 2 3 4 10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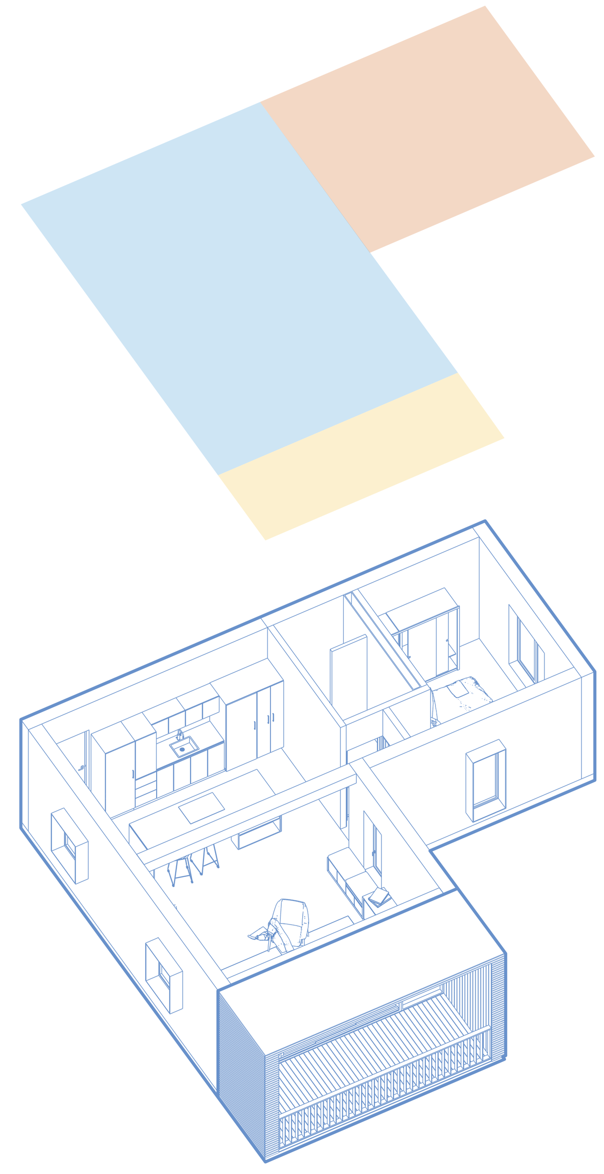

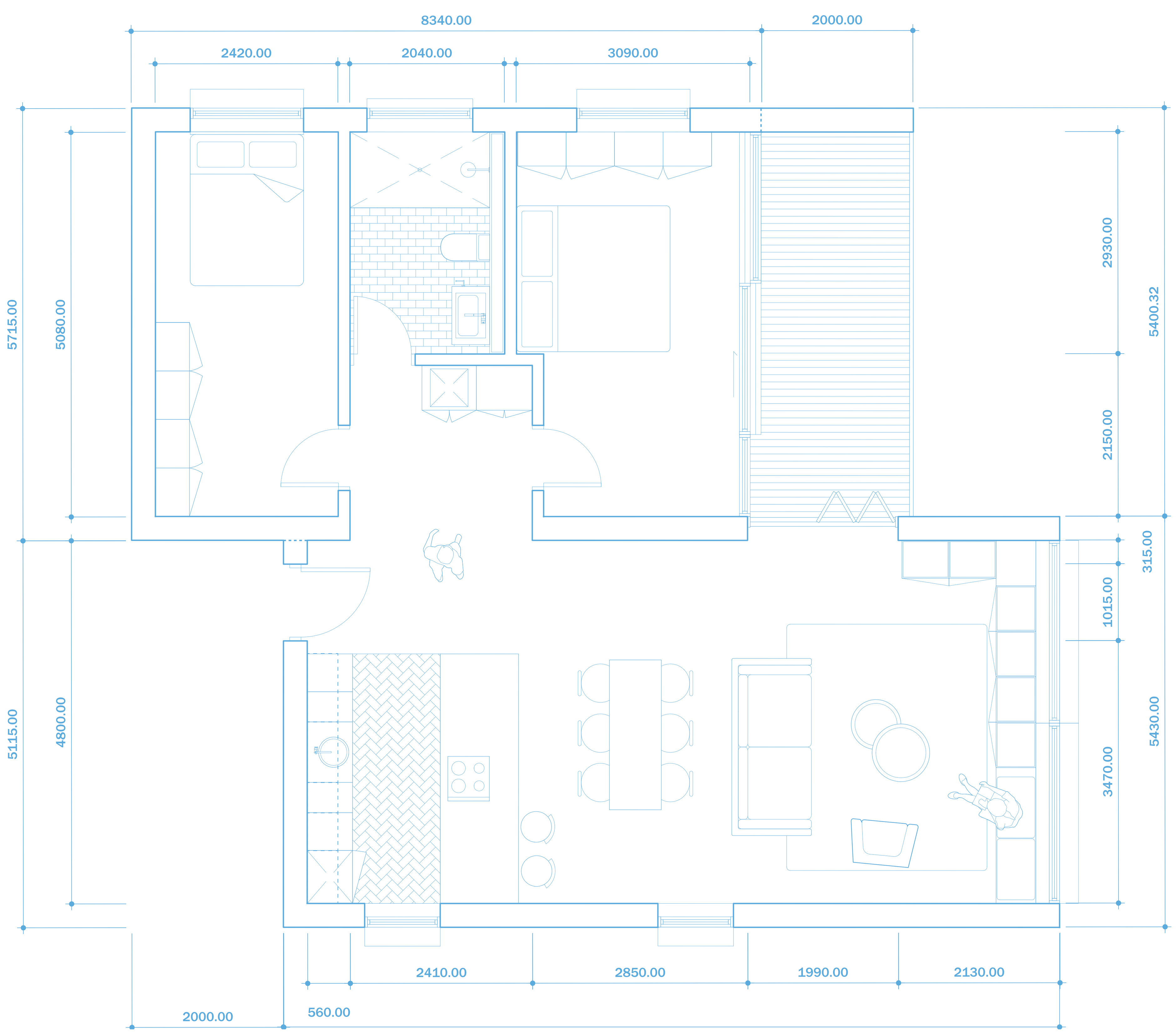
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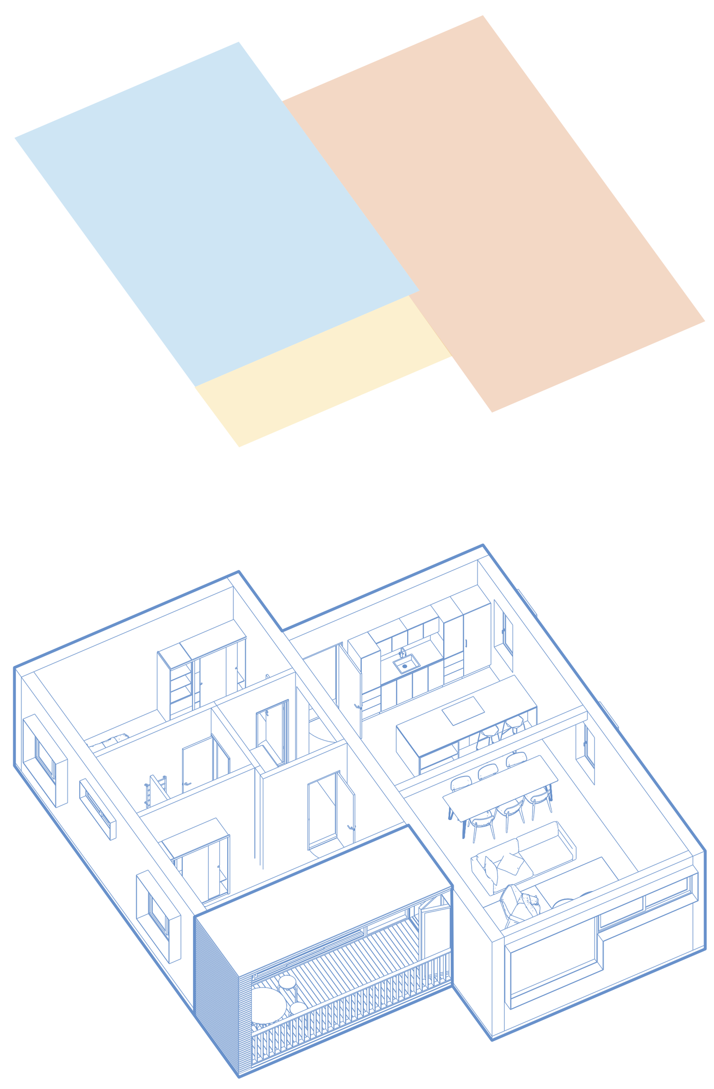
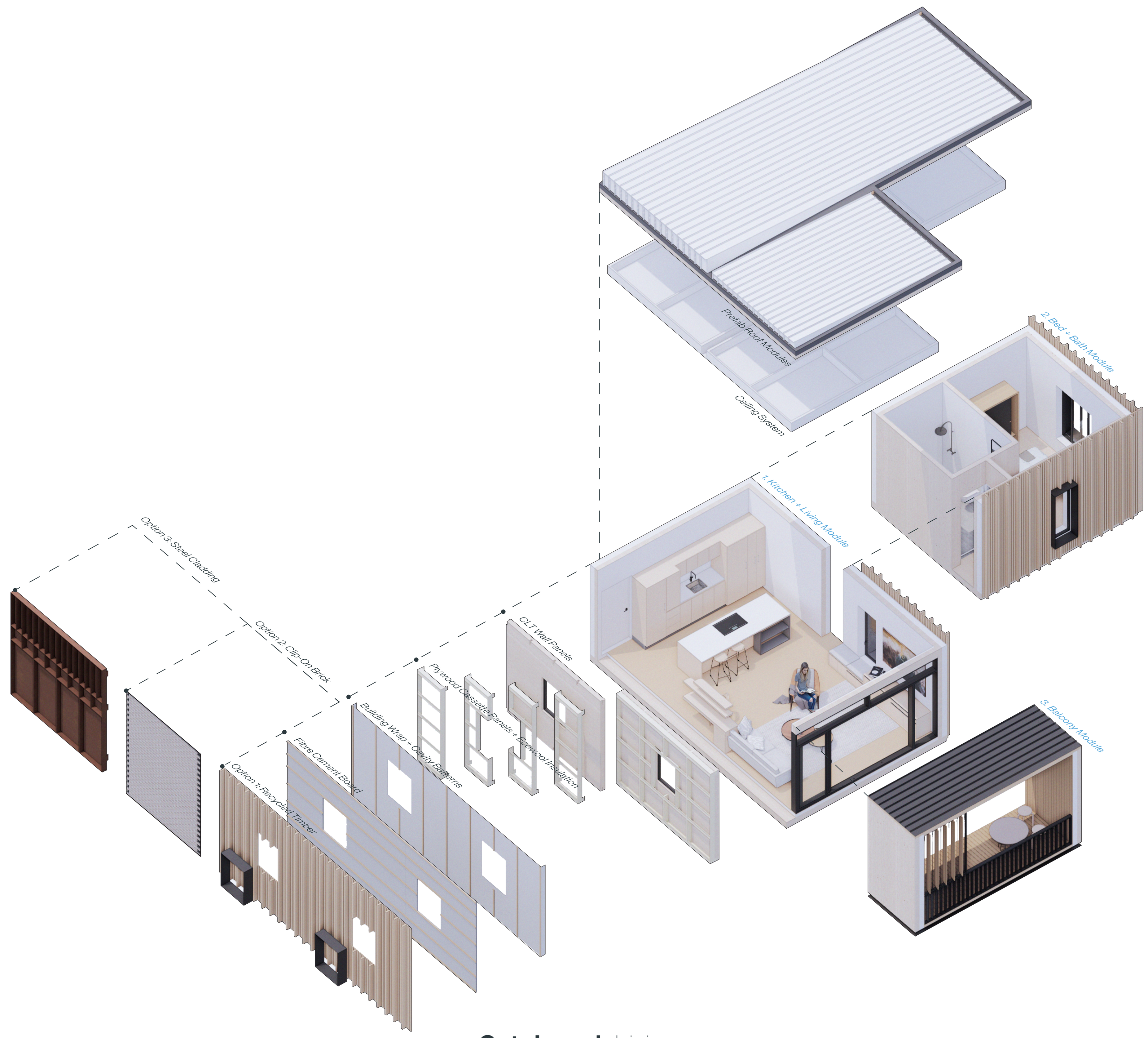


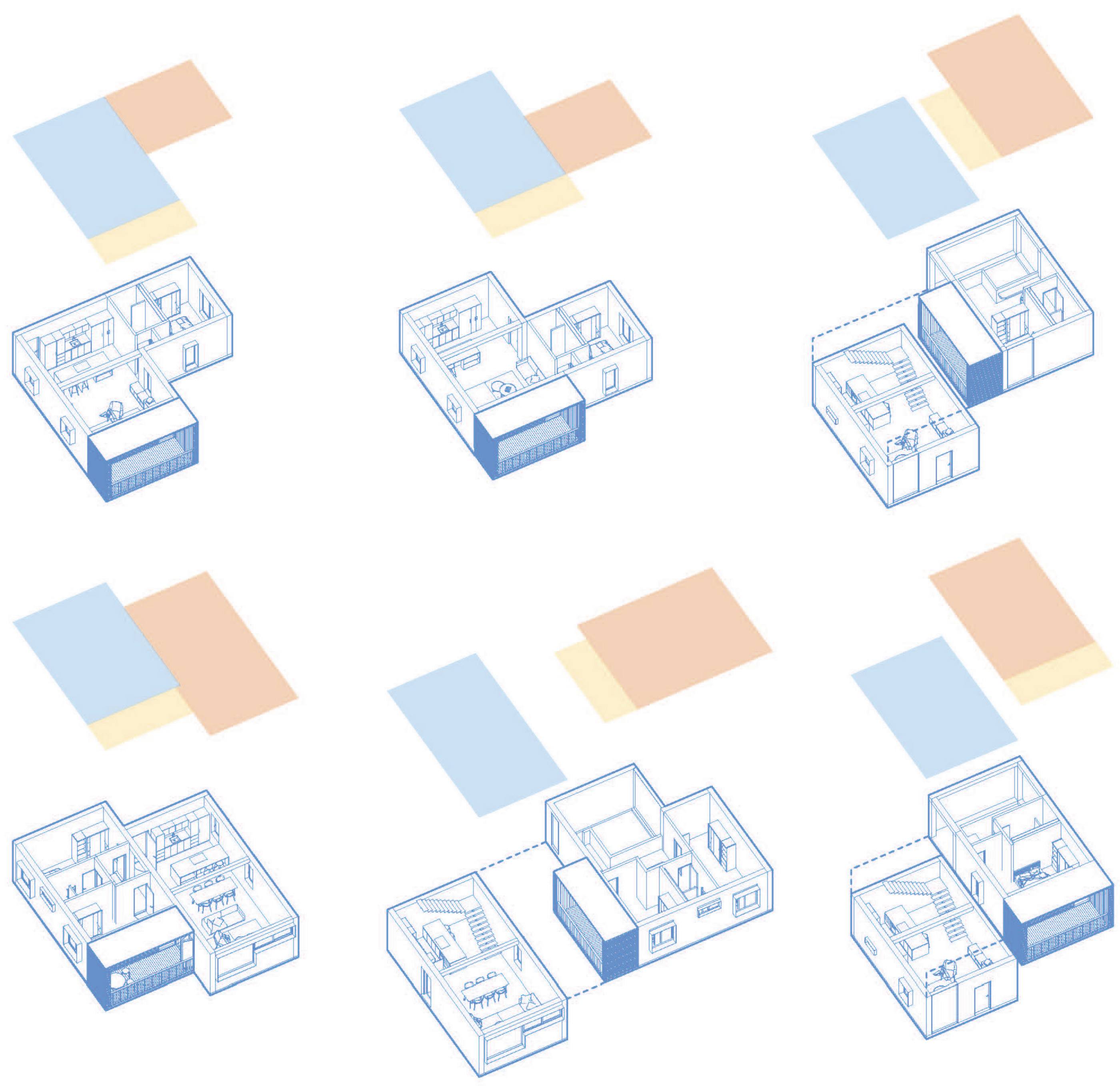


Cataloged Living

The module can be clearly examined through a cataloging of rooms and spaces to formulate a complete home. The modules are not restrictive in its access to natural sunlight and cross ventilation. The integrated balcony doubles as shading device that blocks out harsh sunlight from the summer solstice through a sloped ceiling, yet allows for ample winter solstice light to fill the main living space of the apartment. Carefully placed openings have been implemented to promote cross ventilation from the bedroom through to the kitchen, creating less reliance on AC.

Wall Cassettes

The modules feature an innovative external cladding system comprised of CNC cut timber cassettes which attach to the external face of the CLT wall panels to create a more precise, and systematic approach to the way in which the external systems are designed and costed. This system allows for multiple external cladding options, and doesn't limit the modules into a state of repetition but provide them with a uniqueness in its aesthetic.

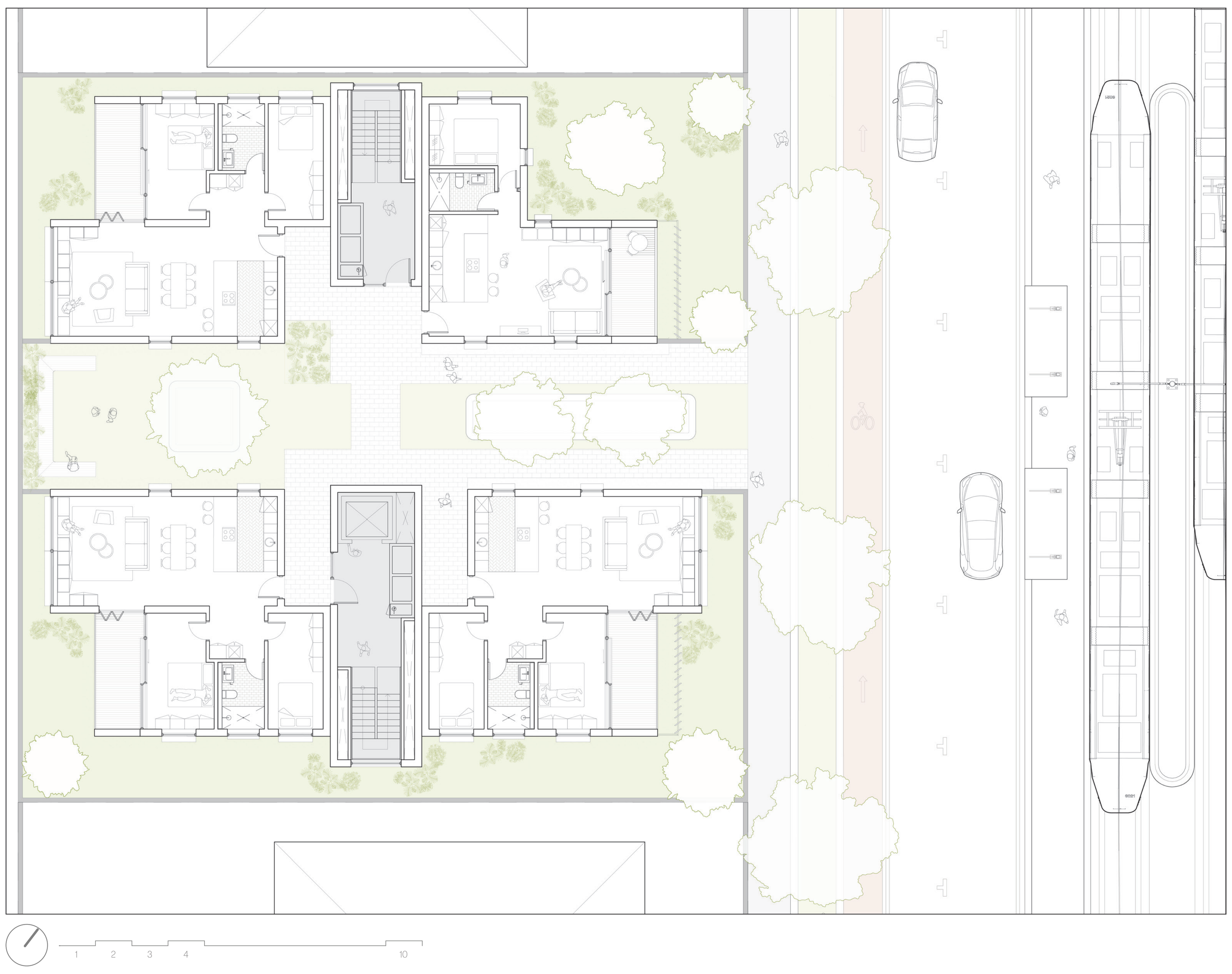


3x3 Concept - Design Variations

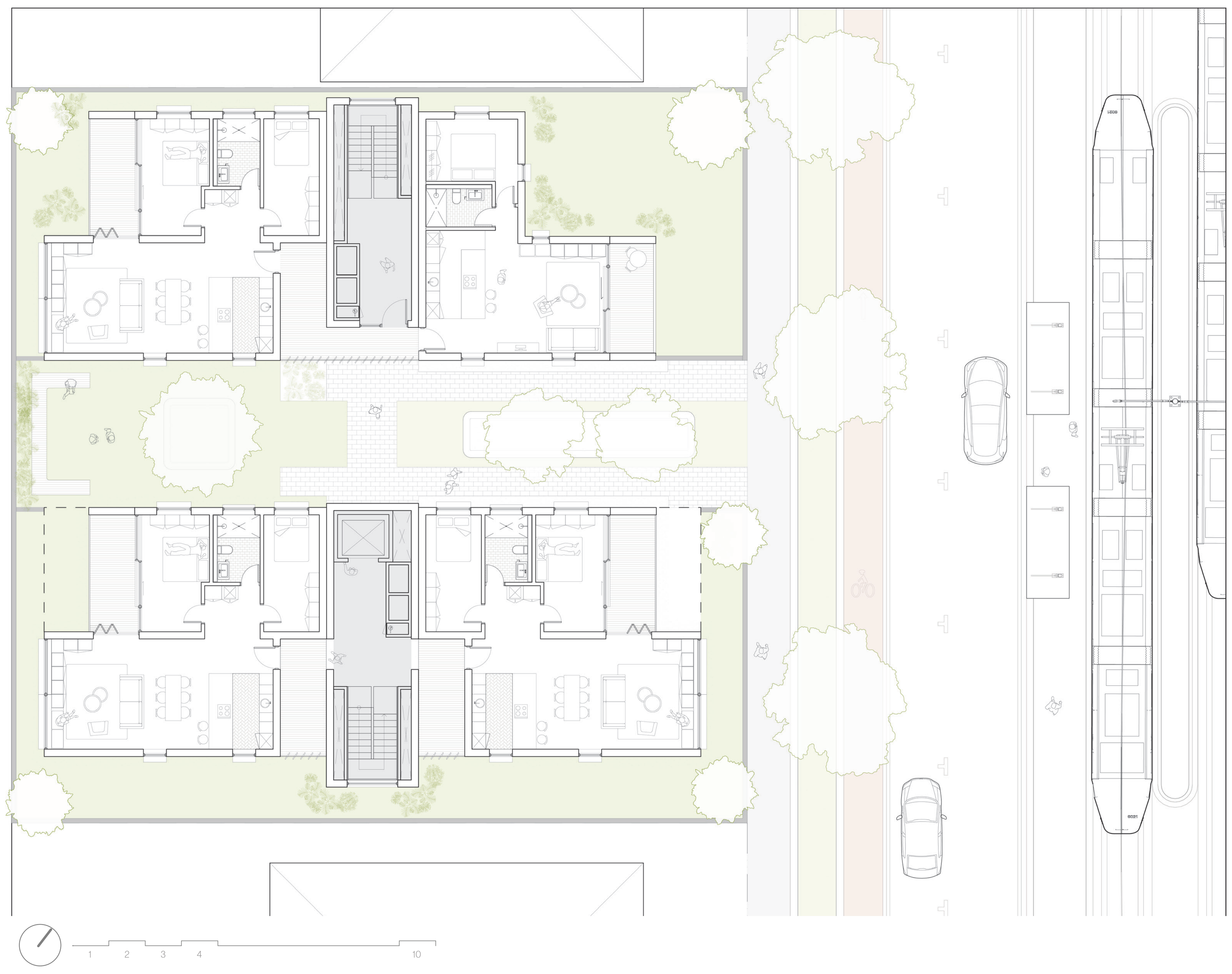
Living + Kitchen

Bedroom + Bathroom

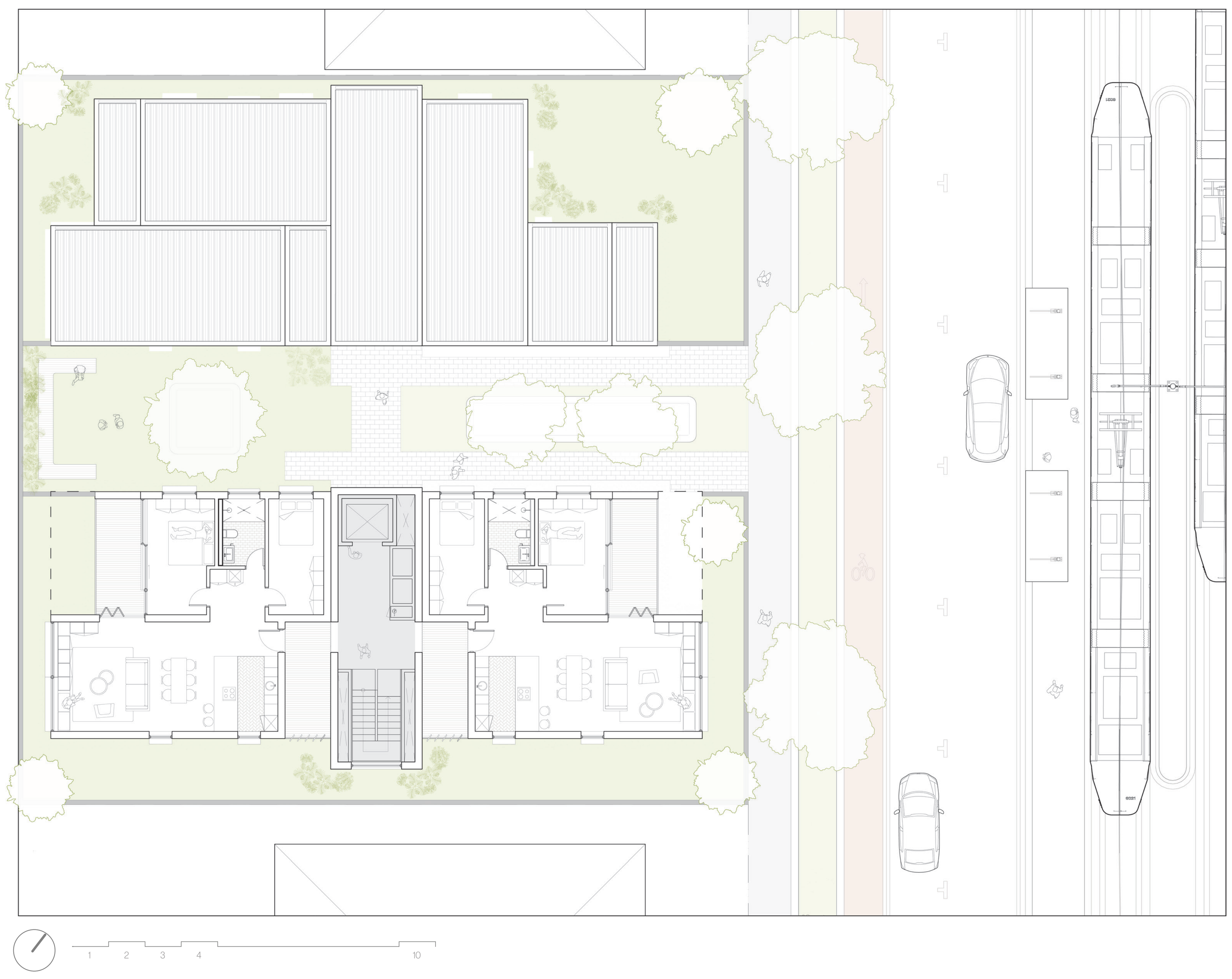
Balcony



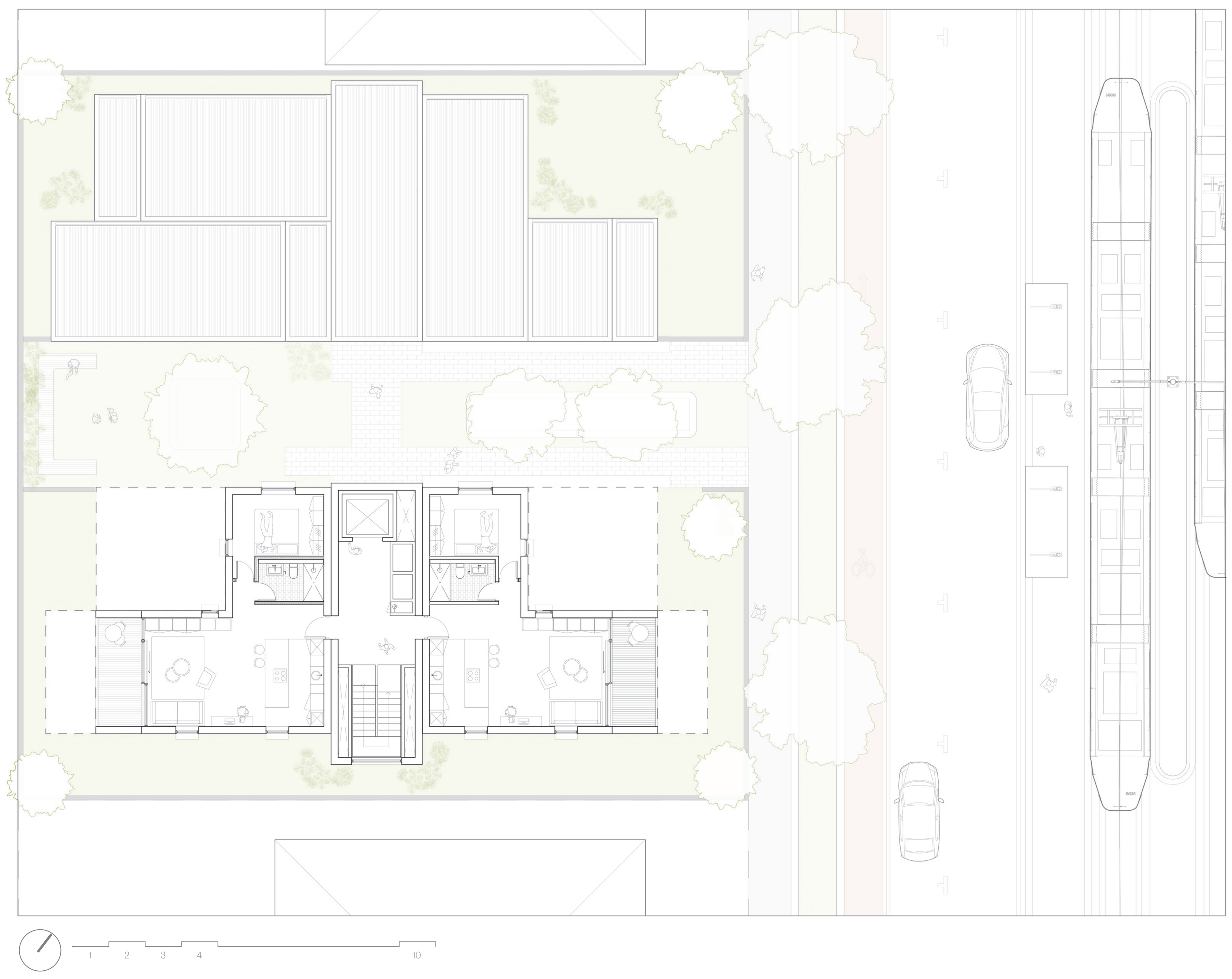
Ground - Floor Plan
Scale 1:100



First- Floor Plan
Scale 1:100



Second - Floor Plan
Scale 1:100



Third - Floor Plan
Scale 1:100

North Sectional - Perspective

3x3haus

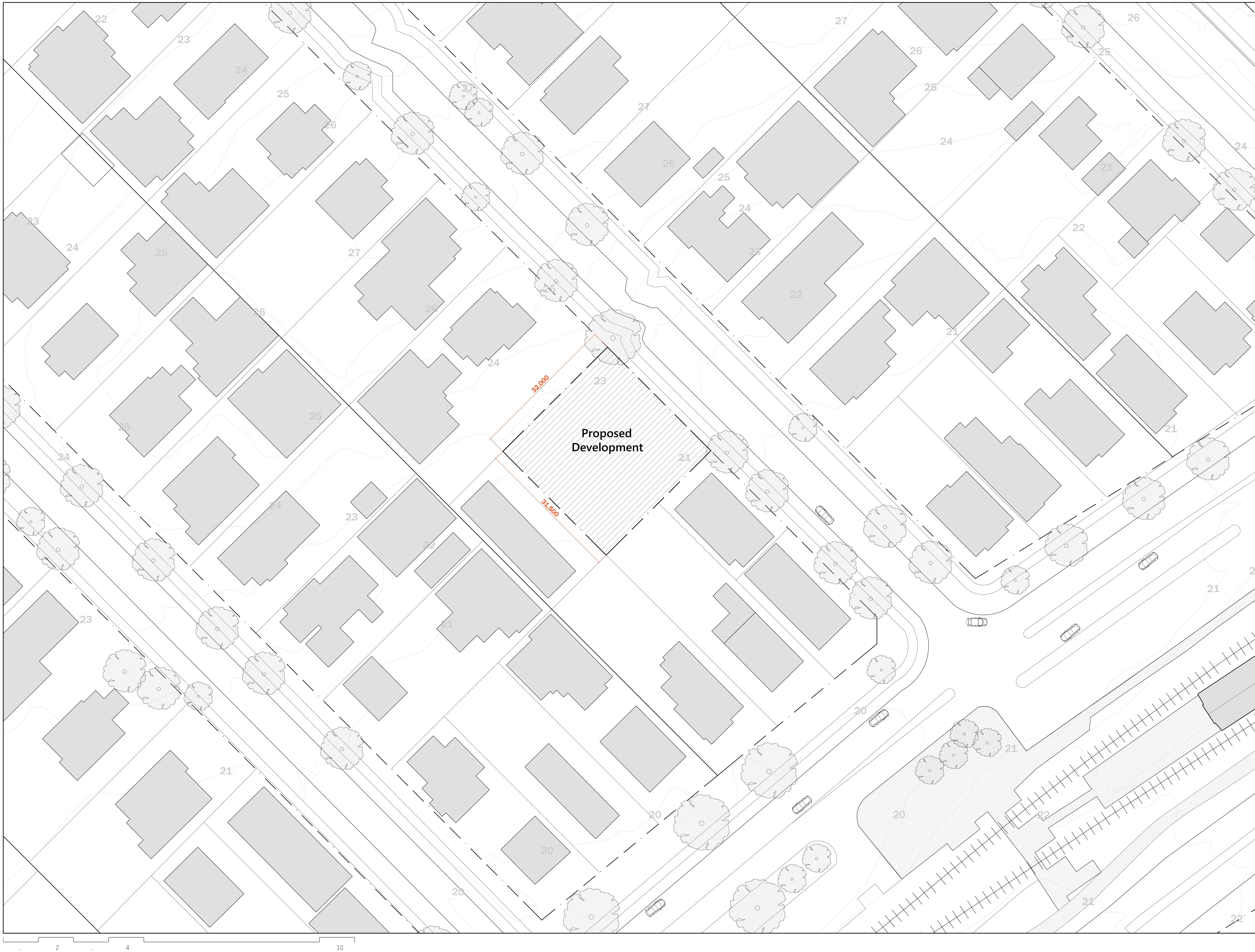





Project Moodboard





JF
AO

General Notes:

- Total Site SQM = 1000m²

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 04/04/2020

Notes:
1.

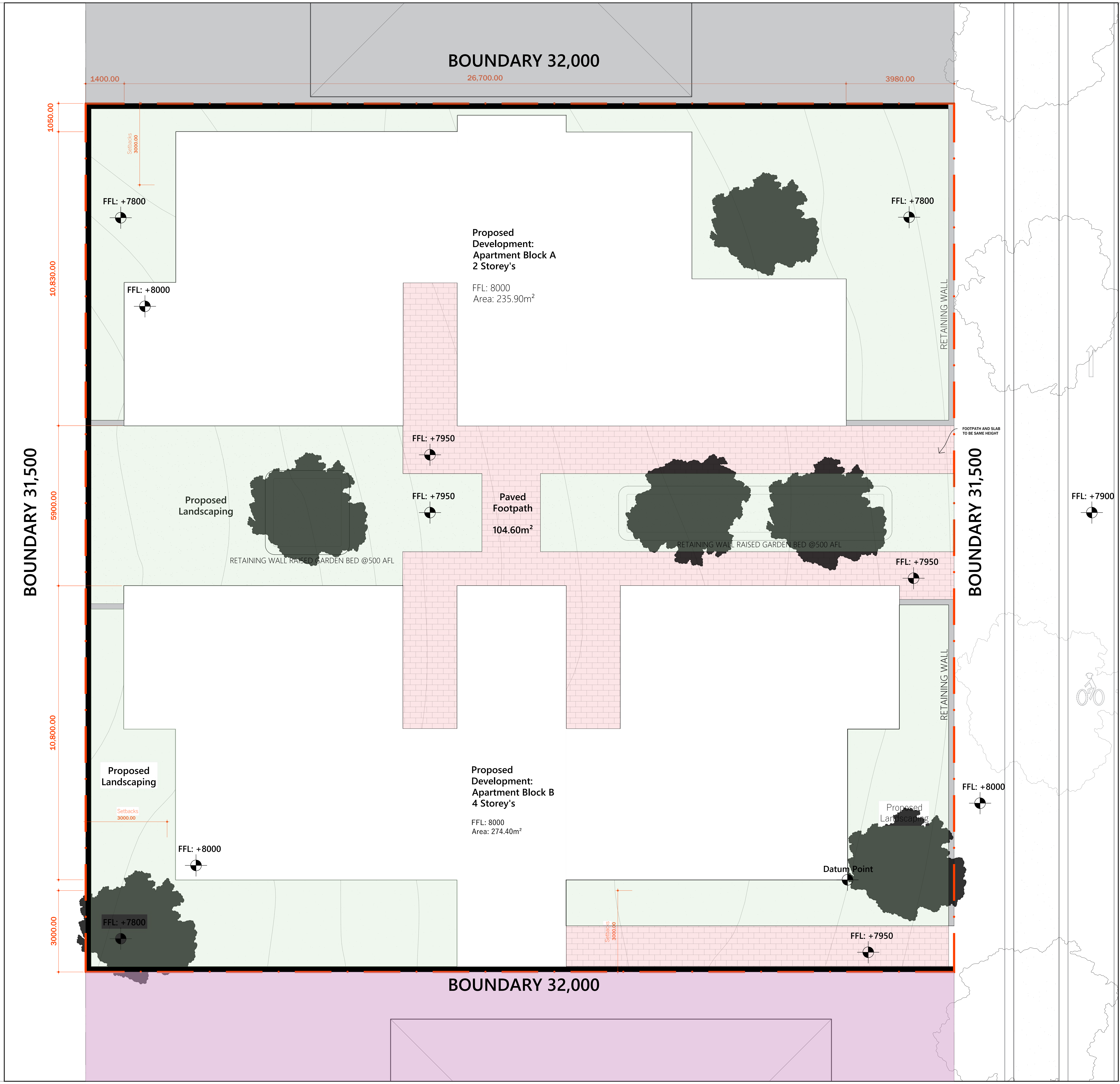
Location Plan

Scale: 1:500 @ A2

Drawing ID: A-00

Drawn by:

A-00



JF
AO

Development Requirements

SCA-15 Planning Guidelines

Total Site SQM = 1000m2

Lot Boundary Setbacks

North Setback
to Side & Rear Boundary

(abutting sites within the Frame Precinct)

GF = NIL
2nd - 3rd Storey = Min 3m Setback
4th+ = Min 6m Setback

South Setback
to Side & Rear Boundary

(abutting sites within the Mixed-Use Core and Residential Core Precinct)

1st - 2nd Storey = NIL
3rd & 4th Storey = Min 3m Setback

Primary Street Setbacks

1st - 4th = 3m (min & max).
Minor variations are permitted to achieve articulation.

Landscaping

Landscaping Minimum landscaping of 25% of the site area, and this is not to include landscaping above the ground level.

Total Landscaping Ground Floor coverage: 367.70m²

Total Landscaping Percentage = 36.7%

Notes:

- Overshadowing direction of June 22nd at 12pm (Noon)
- Contours on site are representative of Fleetwood competition site guidelines and not that of Basywater Site Location.
- Existing site is to be leveled flat as shown in FFL, re-use existing site to back fill for foundations of the new FFL's, providing it complies with geotechnical report.
- On-site services SQM is indicative and not finalized.

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 20/04/2020

Site Plan
Phase:
Construction Documentation

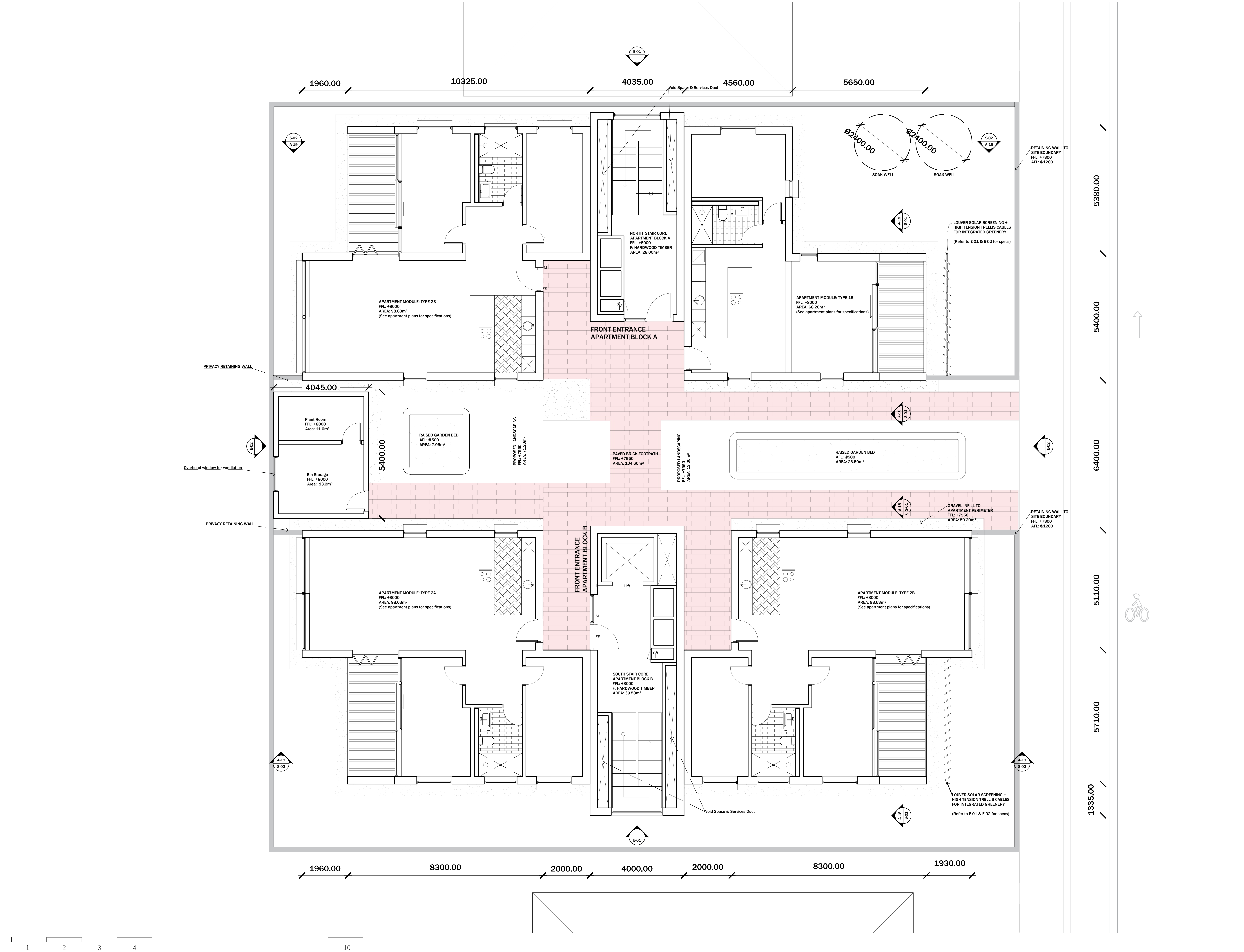
Scale: 1:100 @ A2

Drawing ID: A-01

Drawn by:

A-01

JF
AO



LEGEND

M Mechanical Closet
E Electrical Room
FE Fire Extinguisher

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

Notes:
1.

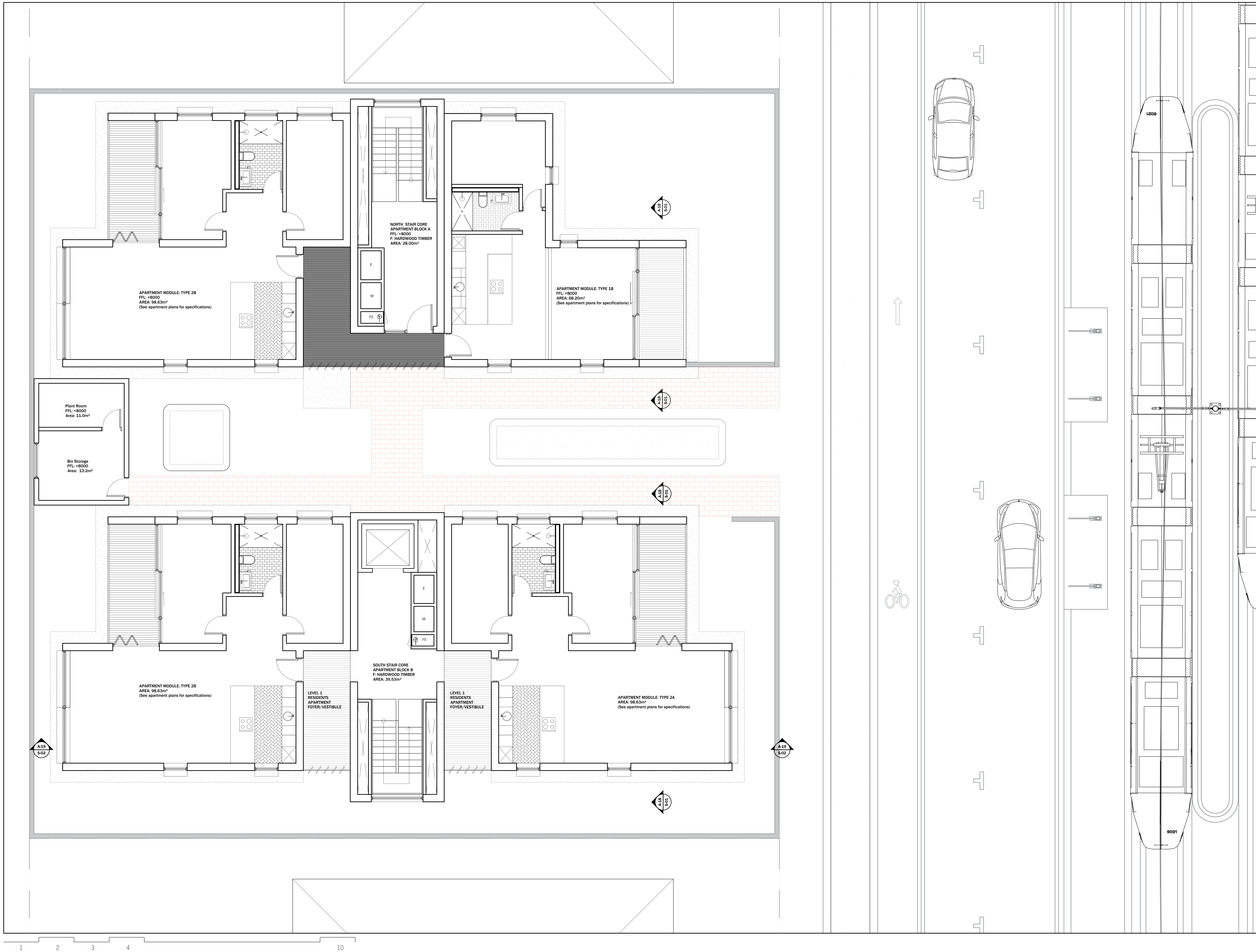
Ground Floor Plan
Phase:
Construction Documentation

Scale: 1:100 @ A2

Drawing ID: A-02

Drawn by:

A-02



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LEGEND

1 Tram Reserve
2. Main Road
3. Bike Path
4. Pedestrian Footpath
5. Central Courtyard
6. Corridor
7. Mailbox
8. Stair Core
9. Elevator

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

Notes:
1.

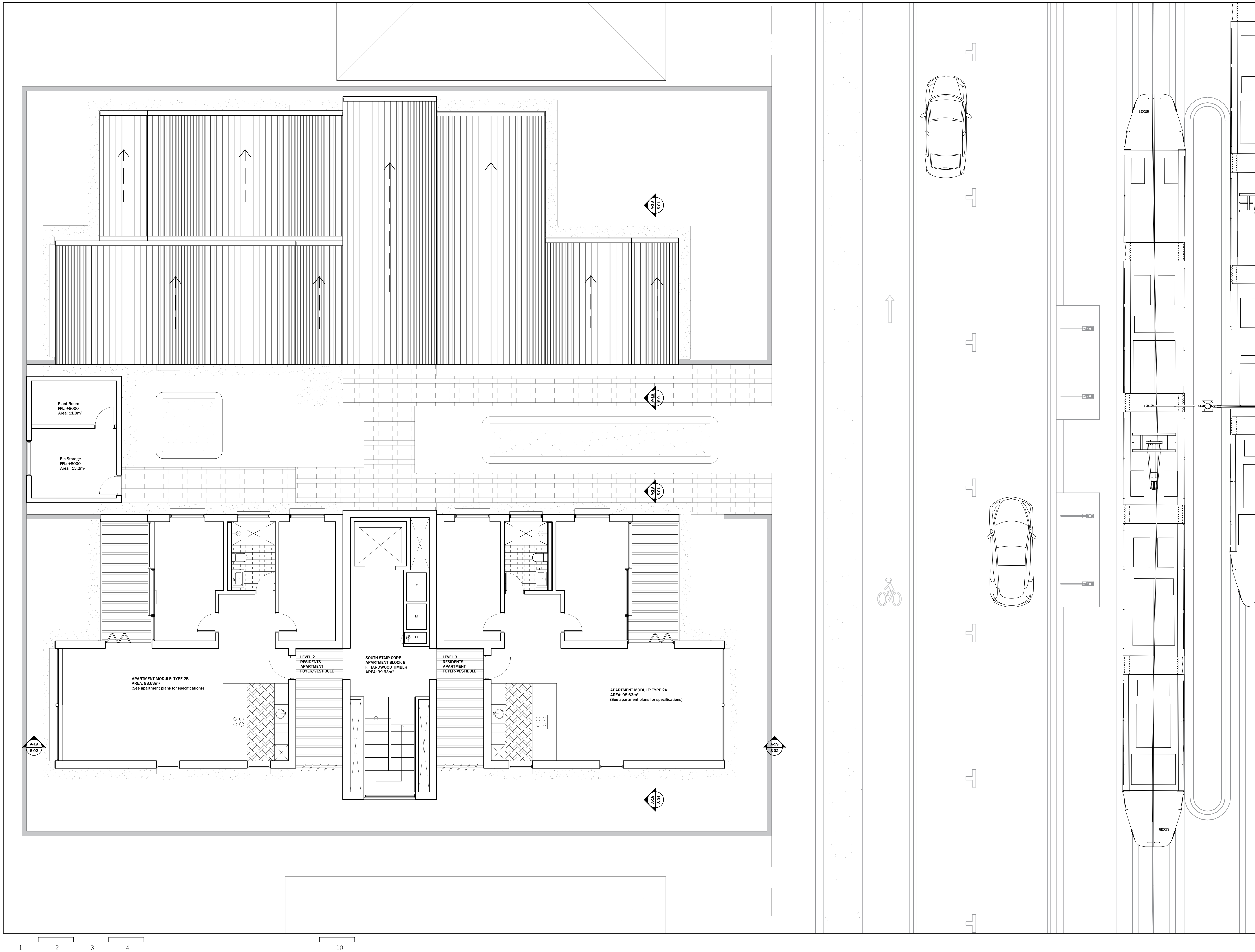
First Floor Plan
Phase:
Construction Documentation

Scale: 1:100 @ A2

Drawing ID: A-03

Drawn by:

A-03



J F
A O

LEGEND

1 Tram Reserve
2. Main Road
3. Bike Path
4. Pedestrian Footpath
5. Central Courtyard
6. Corridor
7. First Floor Roof
8. Stair Core
9. Elevator

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

Notes:
1.

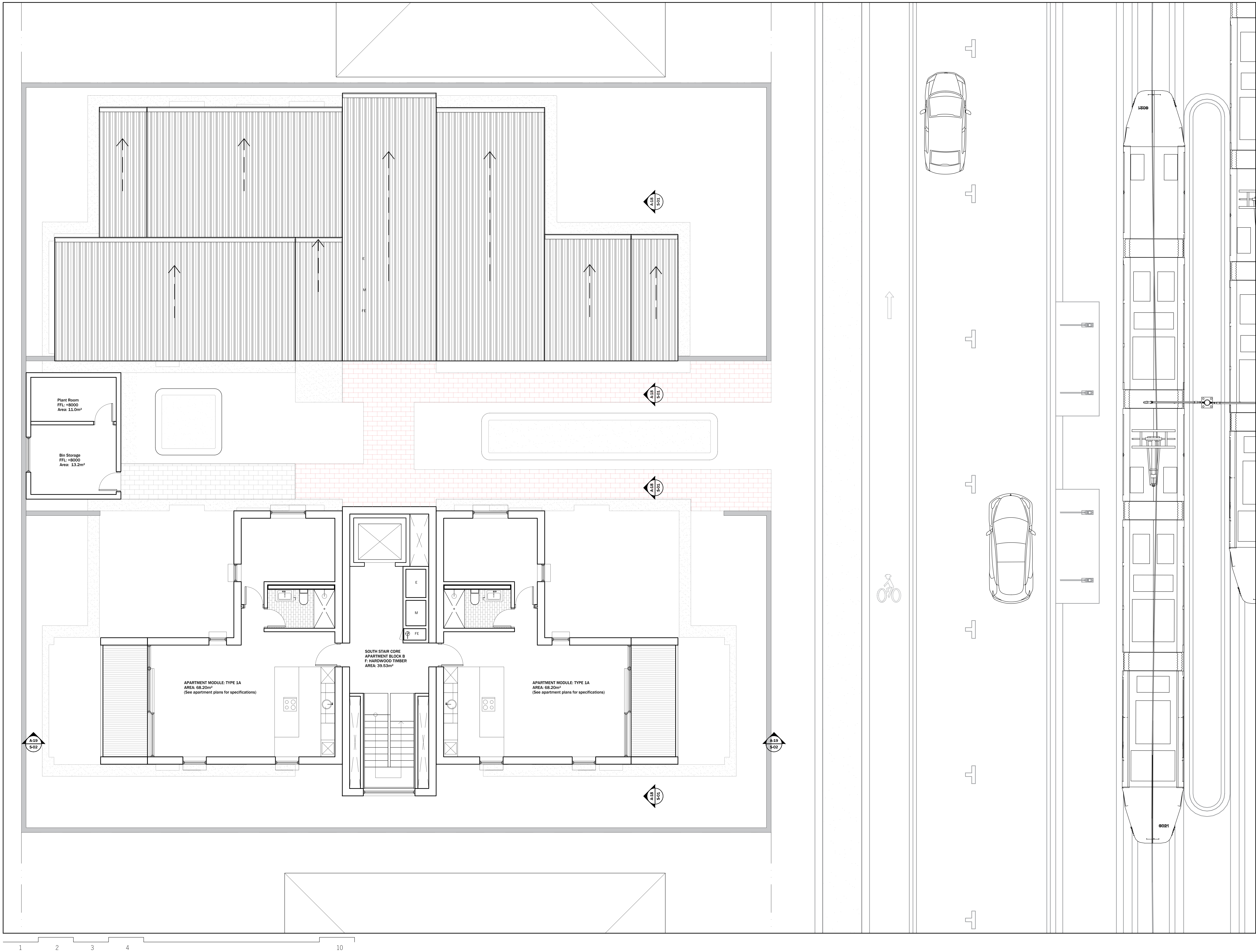
Second Floor Plan
Phase:
Construction Documentation

Scale: 1:100 @ A2

Drawing ID: A-04

Drawn by:

A-04



JF
AO

LEGEND

1 Tram Reserve
2. Main Road
3. Bike Path
4. Pedestrian Footpath
5. Central Courtyard
6. Corridor
7. First Floor Roof
8. Stair Core
9. Elevator

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

Notes:
1.

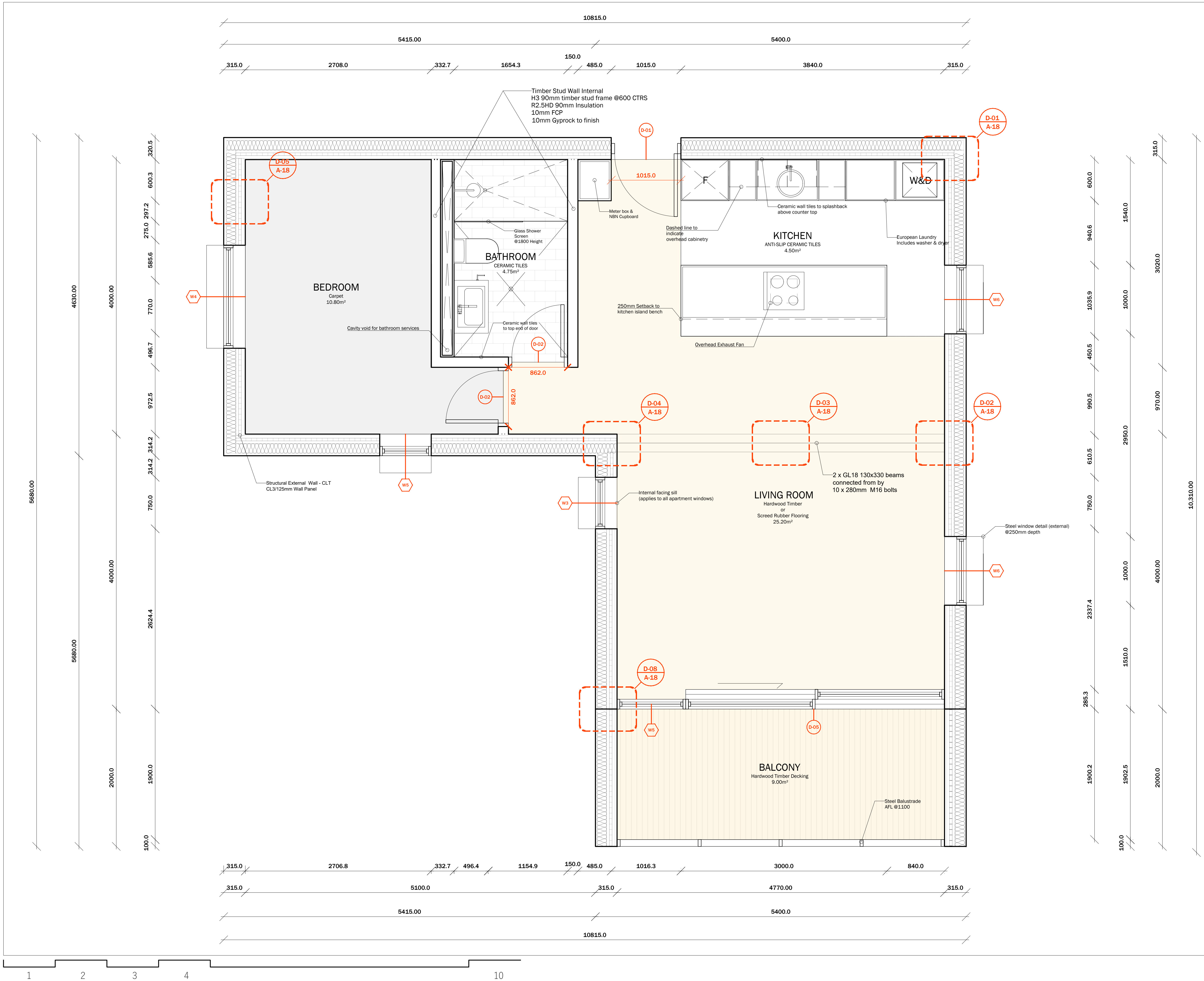
Third Floor Plan
Phase:
Construction Documentation

Scale: 1:100 @ A2

Drawing ID: A-05

Drawn by:

A-05



JF
AO

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

Notes:
1.

Module Type: 1A
1 Bed + 1 Bath
Apartment Plan

Module m² = 59.80
Balcony m² = 8.40

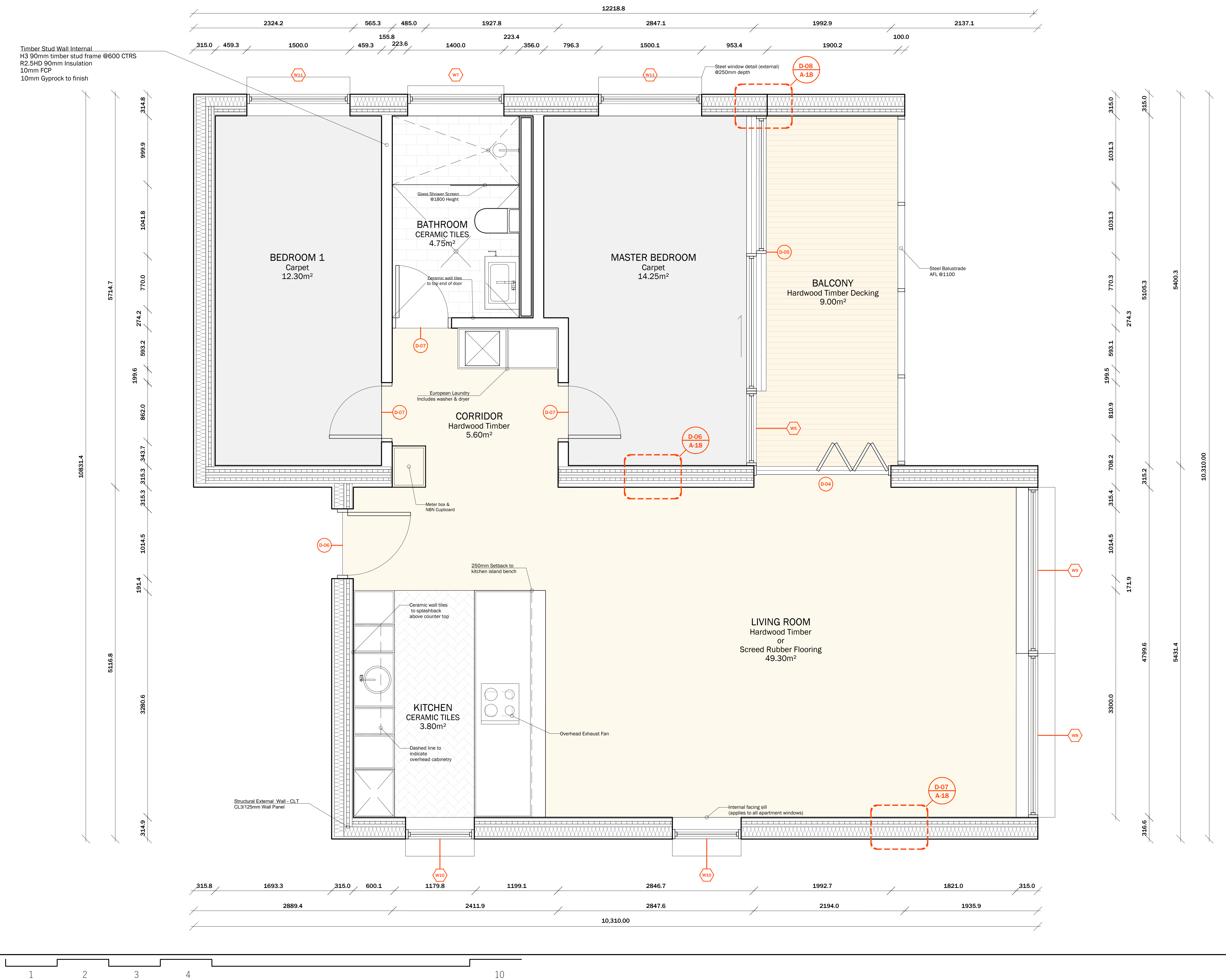
Total m² = 68.20

Scale: 1:50 @ A3

Drawing ID: A-06

Drawn by:

A-06



J F
AO

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

Notes:
1.

Module Type: 2A
2 Bed + 1 Bath
Apartment Plan

Module m² = 89.14
Balcony m² = 9.49
Total m² = 98.63

Scale: 1:50 @ A3

Drawing ID: A-08

Drawn by:

A-08

FOR REFERENCE ONLY

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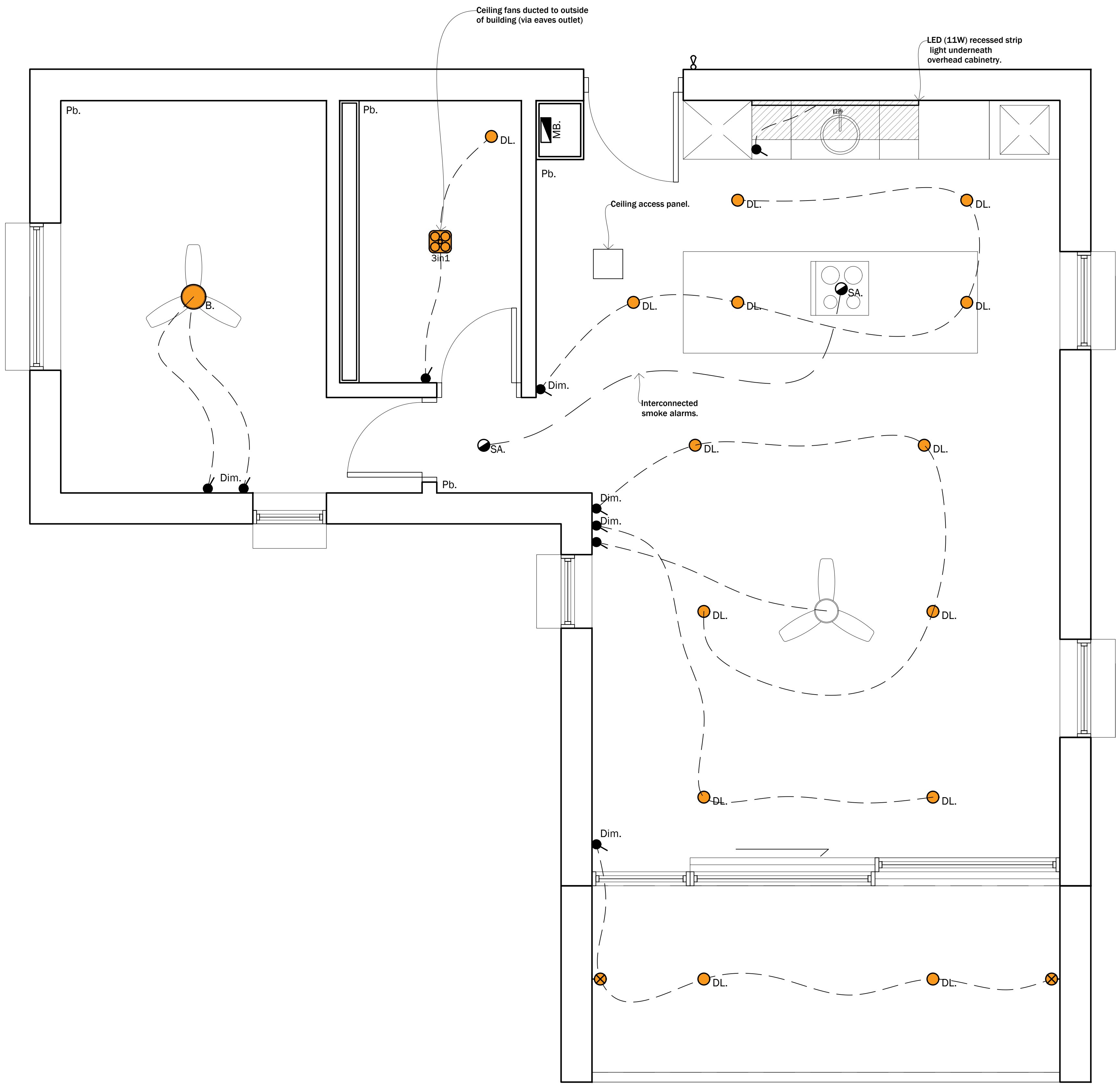

Additional Notes

- All lights to be LED's
- Light switches to be @1200 AFL
- Power supply to exhaust fans, oven, cooktop rangehood TBC
- smoke alarms are to be interconnected & use scatter light, transmitted light or ionization.
- All exhaust wall fans are to be mechanical
- Height dimensions from ground level FFL, confirm onsite
- Dishwasher & washing machine GPO's to be in cabinetry next to appliance void for access

1 2 3 4 10

JF
AO

Legend & Notes

Pb. Plasterboard lining

Maximum Ceiling support spacing = 600mm

Light switch (2w = 2 way switch) (Dim = dimmer)

MB. Meter box & NBN cupboard

SA. Smoke alarm, hard wired with battery backup, To AS 3786 and Part 3.7.2 of current BCA.

External sensor (to meet BCA requirement that external lights be controlled by a daylight sensor).

B. Surface mounted batten light fitting with 11W LED globes.

DL. Recessed LED down light (11W)

3in1 Combination light, fan & heat lamp unit (4 lamp). 4 x 275W heat lamps 1 x 15W fluorescent globe

LED Up/Down exterior wall light (12W) mounted at 1800mm AFL.

LED Up/Down interior wall light (16W) mounted at 1800mm AFL.

LED Recessed downlight (11w)

Corsa 3-Blade Ceiling Fan

- Dimmer switches to be installed on lights in bedrooms, living and dining areas.
- External lights must be controlled by a daylight sensor (as or have an average light source efficacy of not less than 40 lumens/W.
- All bathroom fans to be fitted with backdraught dampers /shutters.

Project

3x3haus

Location: 1 Rosebery st, Bayswater

Date: 24/03/2020

Reflected Ceiling Plan

Module Type: 1A
1 Bed + 1 Bath

Phase: Construction Documentation

Scale: 1:50 @ A3

Drawing ID: A-12

Drawn by:

A-12

FOR REFERENCE ONLY

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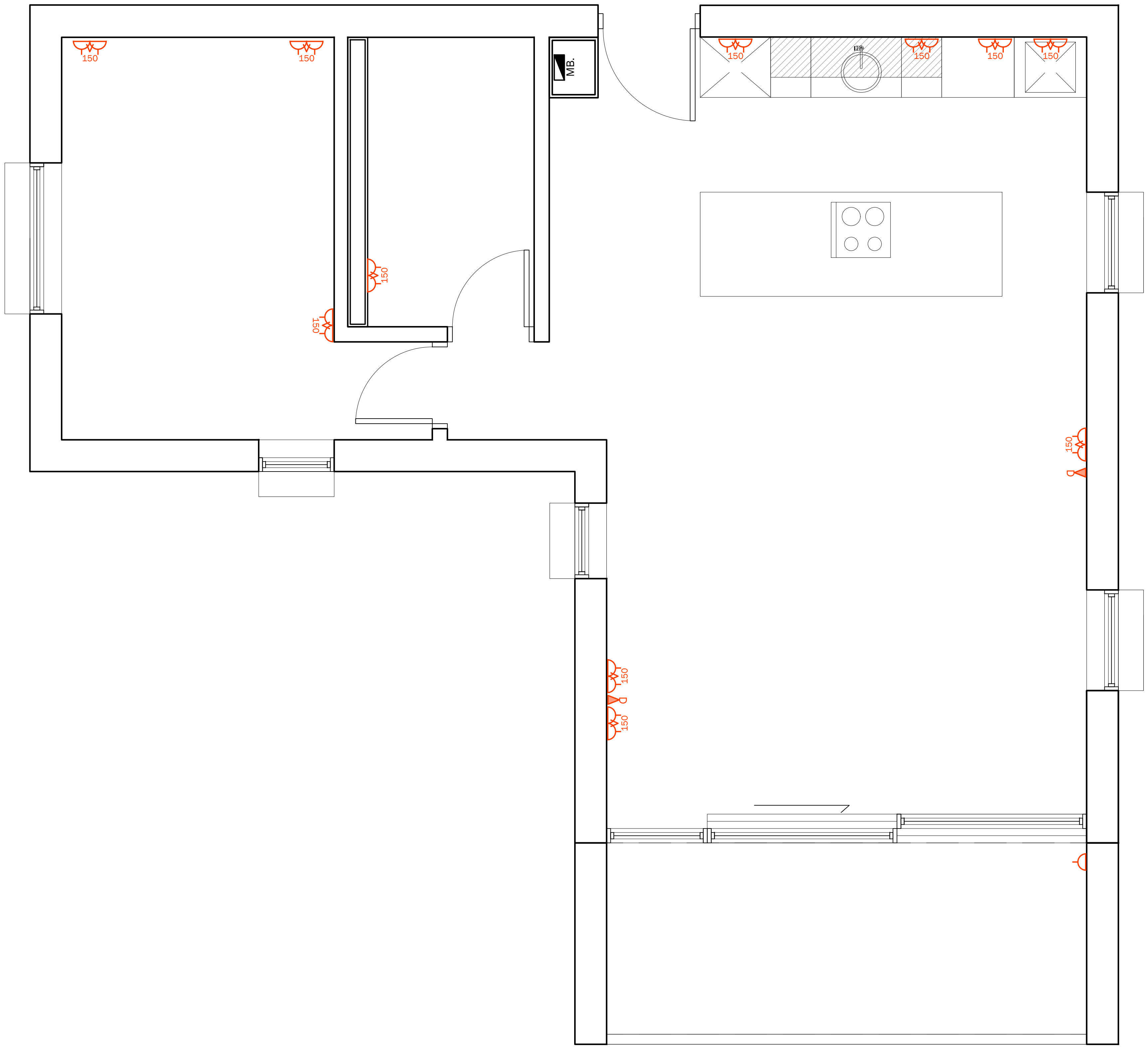
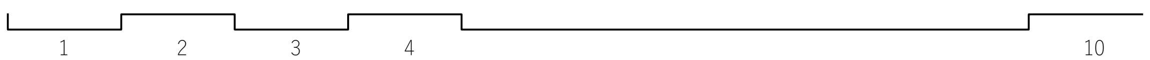


Additional Notes

- All lights to be LED's
- Light switches to be @1200 AFL
- Power supply to exhaust fans, oven, cooktop rangehood TBC
- smoke alarms are to be interconnected & use scatter light, transmitted light or ionization.
- All exhaust wall fans are to be mechanical
- Height dimensions from ground level FFL, confirm onsite
- Dishwasher & washing machine GPO's to be in cabinetry next to appliance void for access



J F
AO

Legend & Notes

- MB. Meter box & NBN cupboard
- Single GPO
- Double GPO
- D Data Point

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

Power & Data Plan

Module Type: 1A
1 Bed + 1 Bath

Phase:
Construction Documentation

Scale: 1:50 @ A3

Drawing ID: A-13

Drawn by:

A-13

FOR REFERENCE ONLY

This drawing is representative of the documentation requirements. The content should not be relied upon as accurate for another building project.

1 2 3 4 10

Additional Notes

- All lights to be LED's
- Light switches to be @1200 AFL
- Power supply to exhaust fans, oven, cooktop rangehood TBC
- smoke alarms are to be interconnected & use scatter light, transmitted light or ionization.
- All exhaust wall fans are to be mechanical
- Height dimensions from ground level FFL, confirm onsite
- Dishwasher & washing machine GPO's to be in cabinetry next to appliance void for access

J F
AO

Legend & Notes

Pb. Plasterboard lining

Maximum Ceiling support spacing = 600mm

Light switch
(2w = 2 way switch)
(Dim = dimmer)

MB. Meter box & NBN cupboard

SA. Smoke alarm, hard wired with battery backup, To AS 3786 and Part 3.7.2 of current BCA.

External sensor (to meet BCA requirement that external lights be controlled by a daylight sensor).

B. Surface mounted batten light fitting with 11W LED globes.

DL. Recessed LED down light (11W)

3in1 Combination light, fan & heat lamp unit (4 lamp). 4 x 275W heat lamps 1 x 15W fluorescent globe

LED Up/Down exterior wall light (12W) mounted at 1800mm AFL.

LED Up/Down interior wall light (16W) mounted at 1800mm AFL.

LED Recessed downlight (11w)

Corsa 3-Blade Ceiling Fan

- Dimmer switches to be installed on lights in bedrooms, living and dining areas.
- External lights must be controlled by a daylight sensor (as or have an average light source efficacy of not less than 40 lumens/W.
- All bathroom fans to be fitted with backdraught dampers /shutters.

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

Reflected Ceiling Plan

Module Type: 2A
2 Bed + 1 Bath

Phase:
Construction Documentation

Scale: 1:50 @ A3

Drawing ID: A-14

Drawn by:

A-14

FOR REFERENCE ONLY

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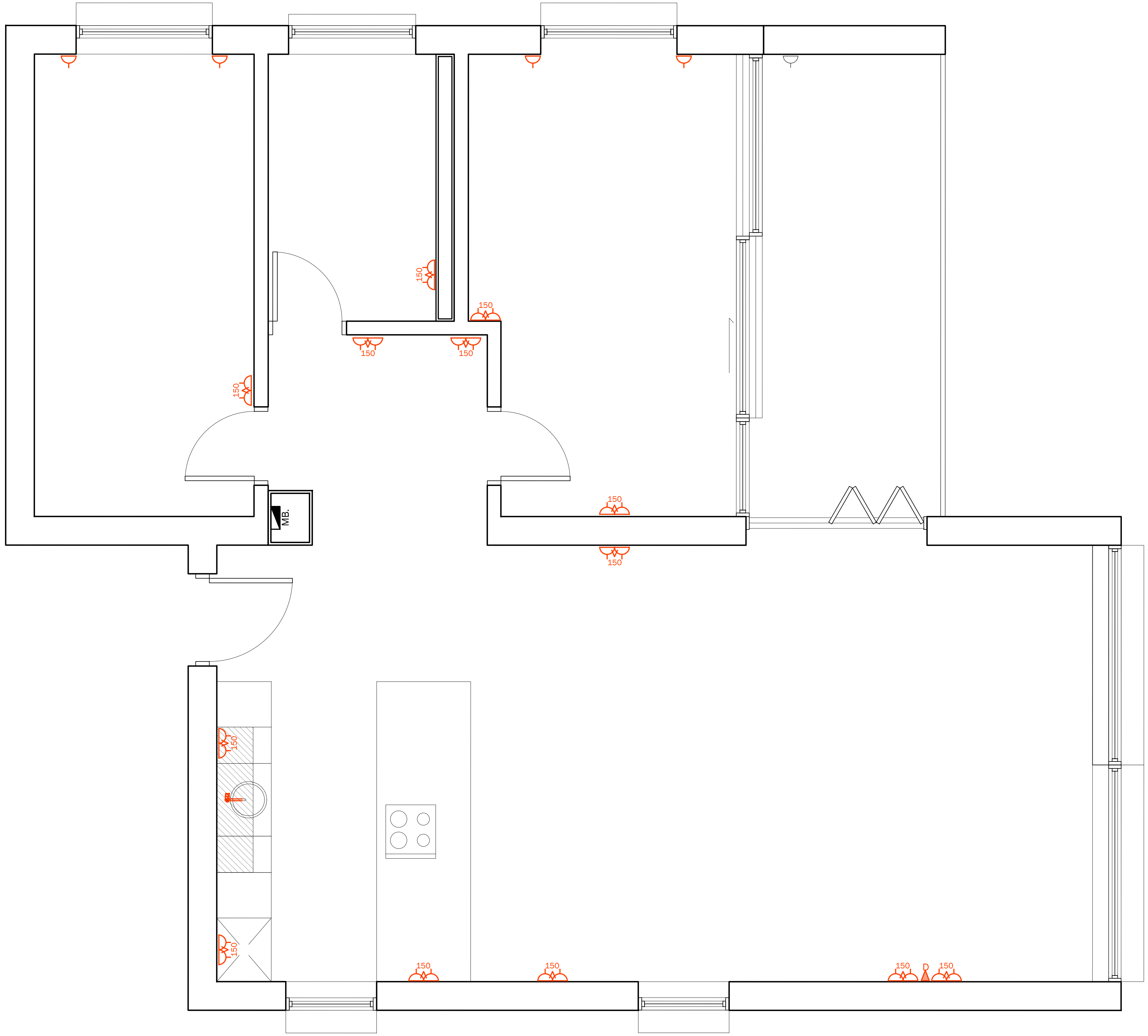


Additional Notes

- All lights to be LED's
- Light switches to be @1200 AFL
- Power supply to exhaust fans, oven, cooktop rangehood TBC
- smoke alarms are to be interconnected & use scatter light, transmitted light or ionization.
- All exhaust wall fans are to be mechanical
- Height dimensions from ground level FFL, confirm onsite
- Dishwasher & washing machine GPO's to be in cabinetry next to appliance void for access

1 2 3 4 10

JF
AO

Legend & Notes

MB.	Meter box & NBN cupboard
	Single GPO
	Double GPO
	Data Point

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

Power & Data Plan

Module Type: 2A
2 Bed + 1 Bath

Phase:
Construction Documentation

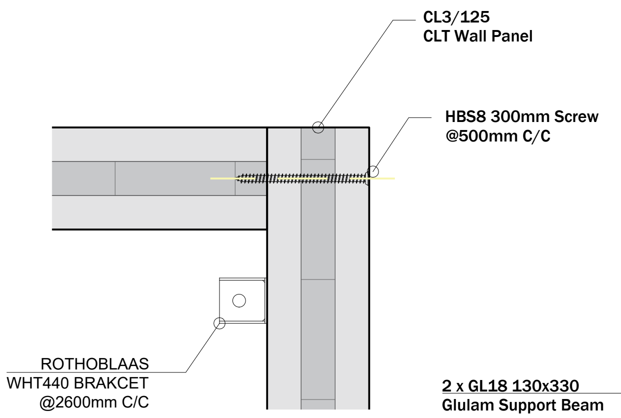
Scale: 1:50 @ A3

Drawing ID: A-15

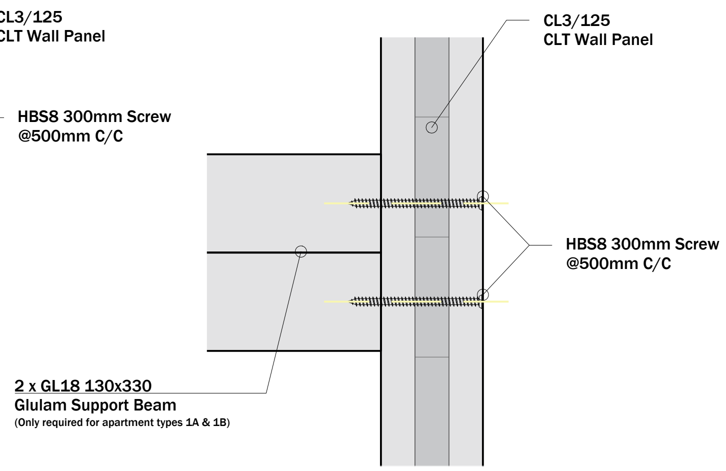
Drawn by:

A-15

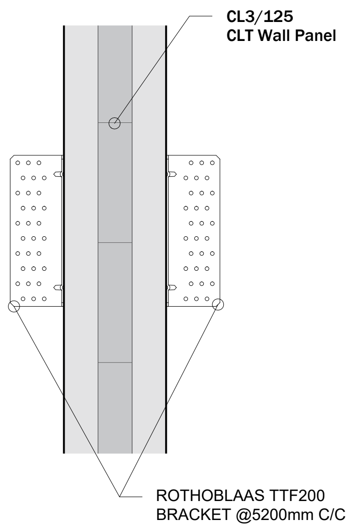
D-01 Corner Joint
SCALE: 1:10



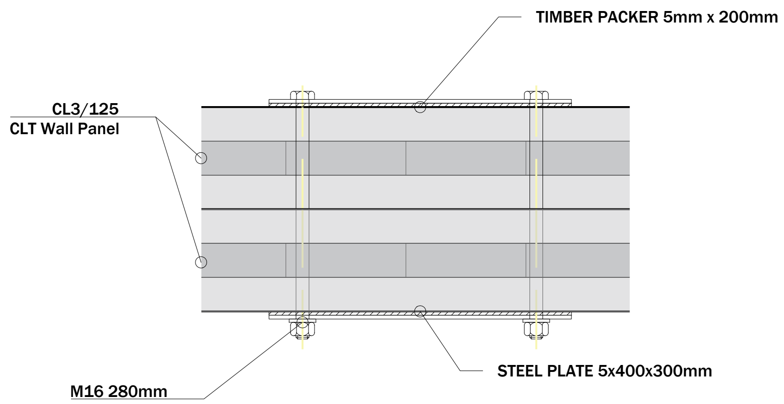
D-02 External Wall to Glulam Support Beam
SCALE: 1:10



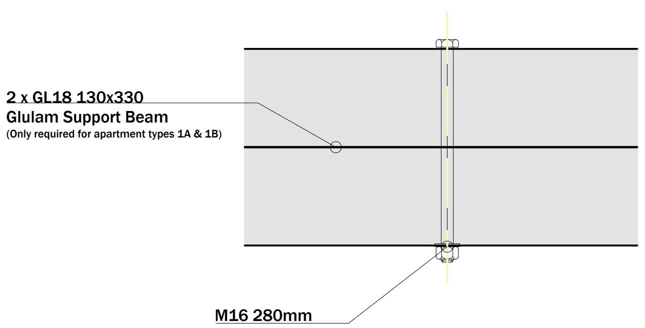
D-05 External Wall to Floor
SCALE: 1:10



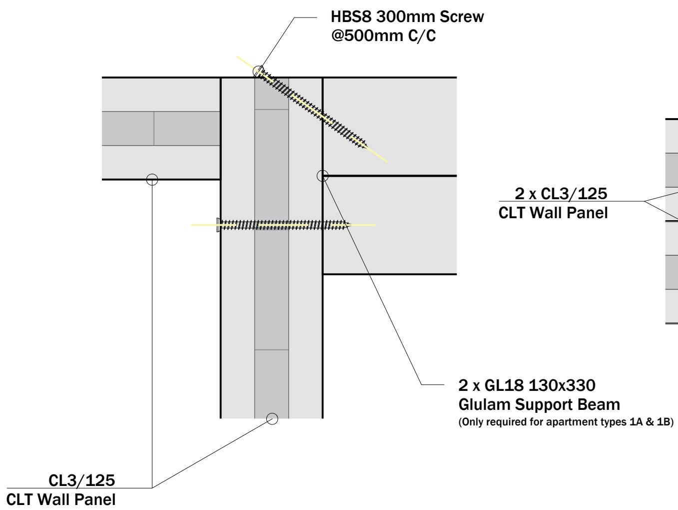
D-06 Module Connection (Wall to Wall)
SCALE: 1:10



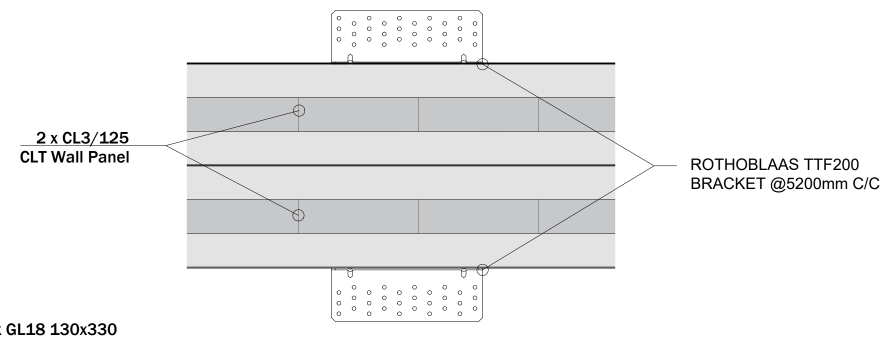
D-03 Glulam Support Beam
SCALE: 1:10



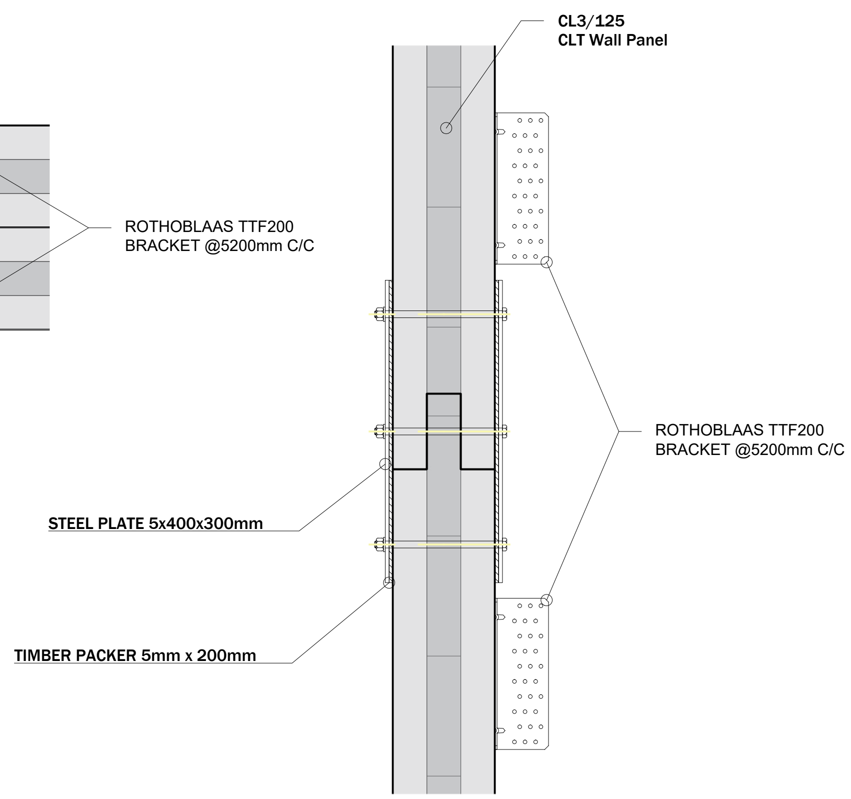
D-04 Corner to Glulam Support Beam
SCALE: 1:10



D-07 Module Connection
SCALE: 1:10



D-08 Apartment Wall to Balcony Wall
SCALE: 1:10



1 2 3 4 10

JF
AO

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

Notes:
1.

CLT Connection Details (Plan View)

Scale: 1:10 @ A3

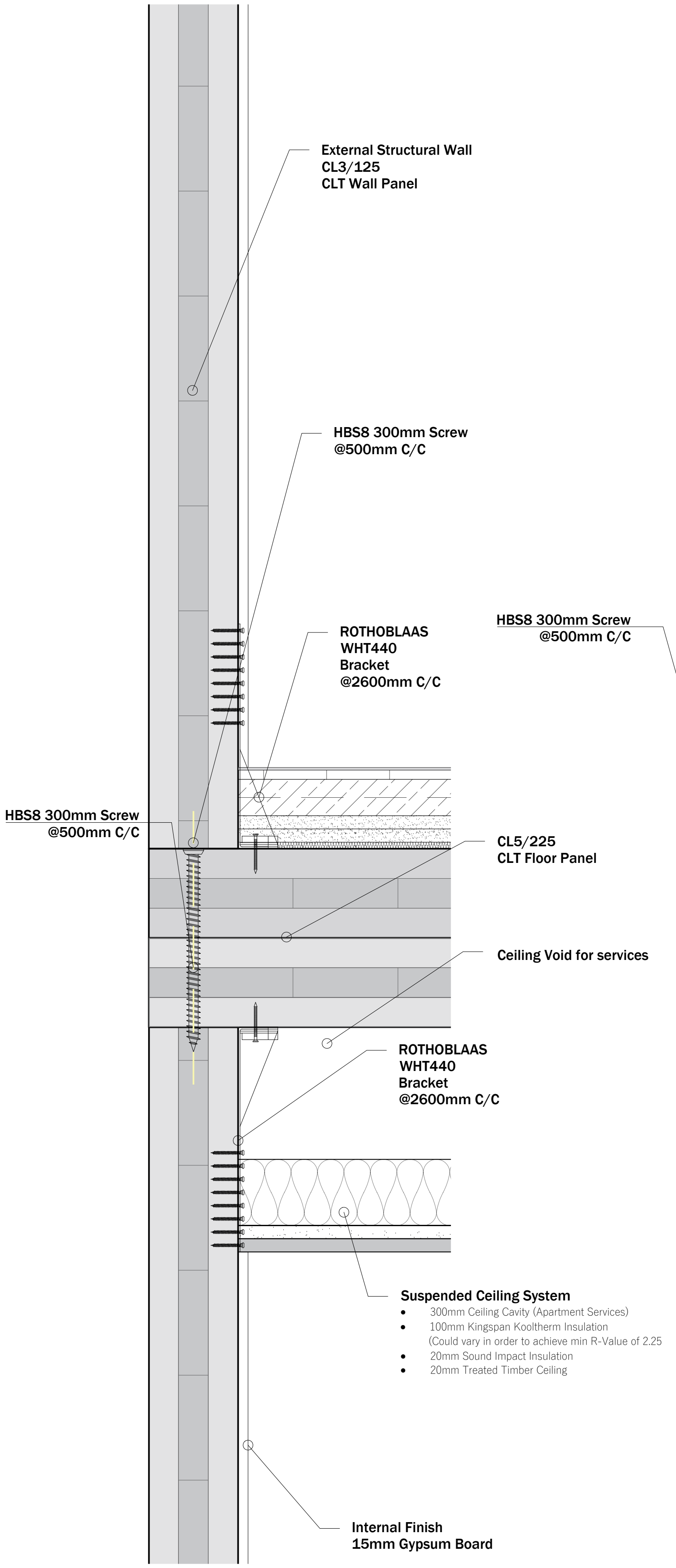
Drawing ID: A-18

Drawn by:

A-18

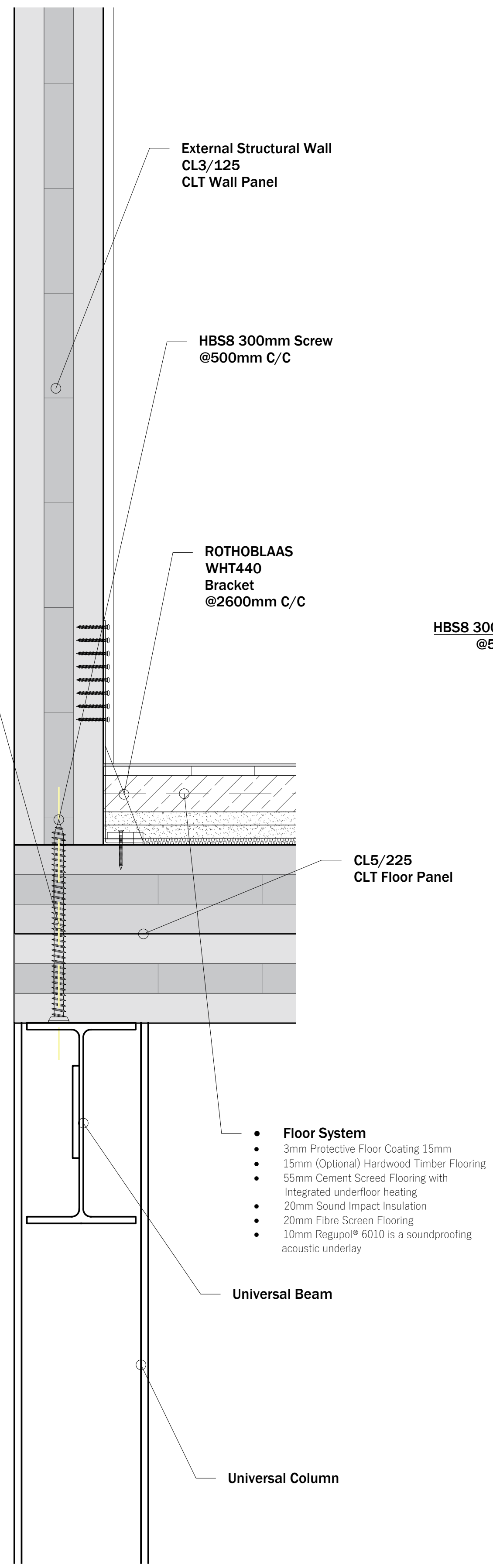
D-09 External Wall to Wall

SCALE: 1:10



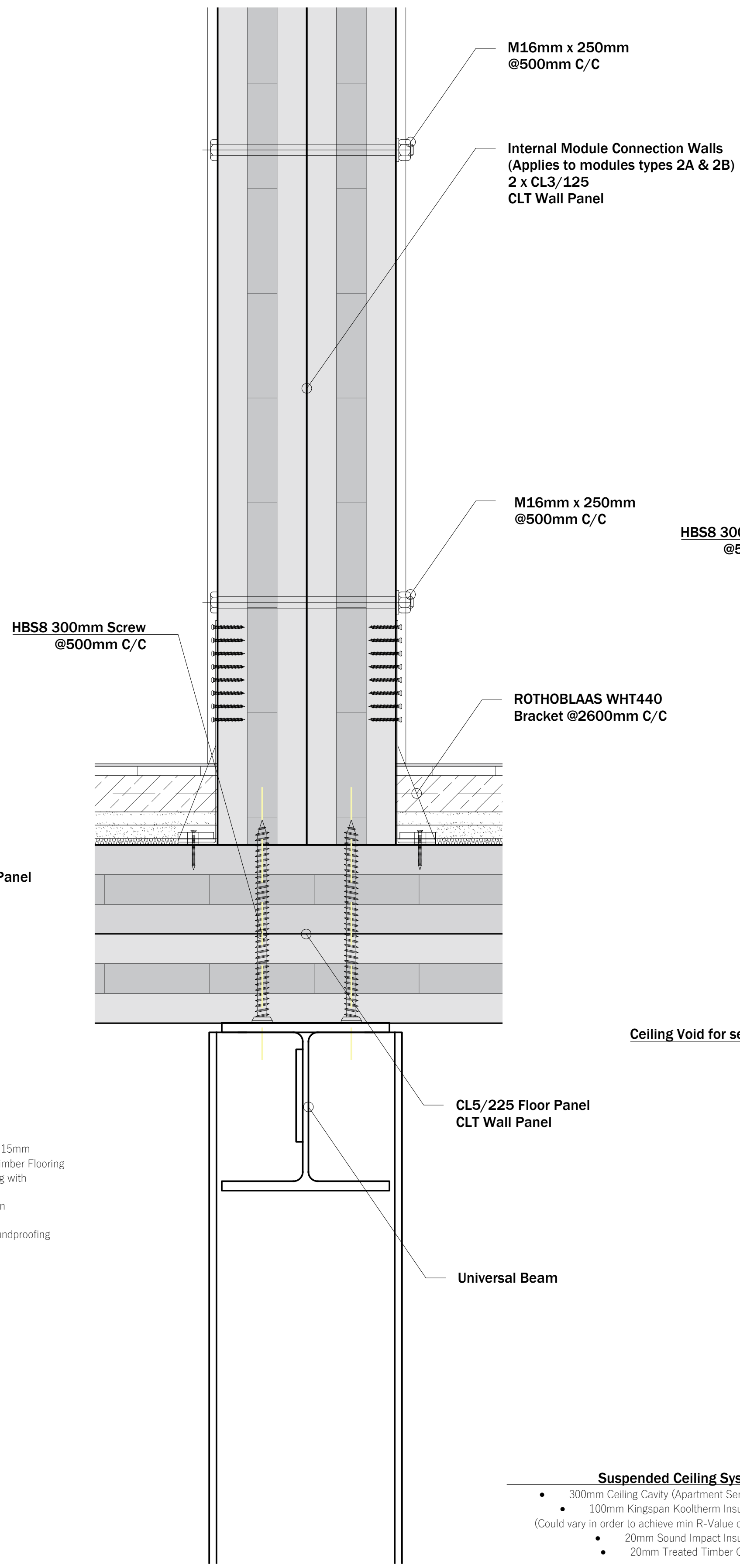
D-10 External Wall to Floor

SCALE: 1:10



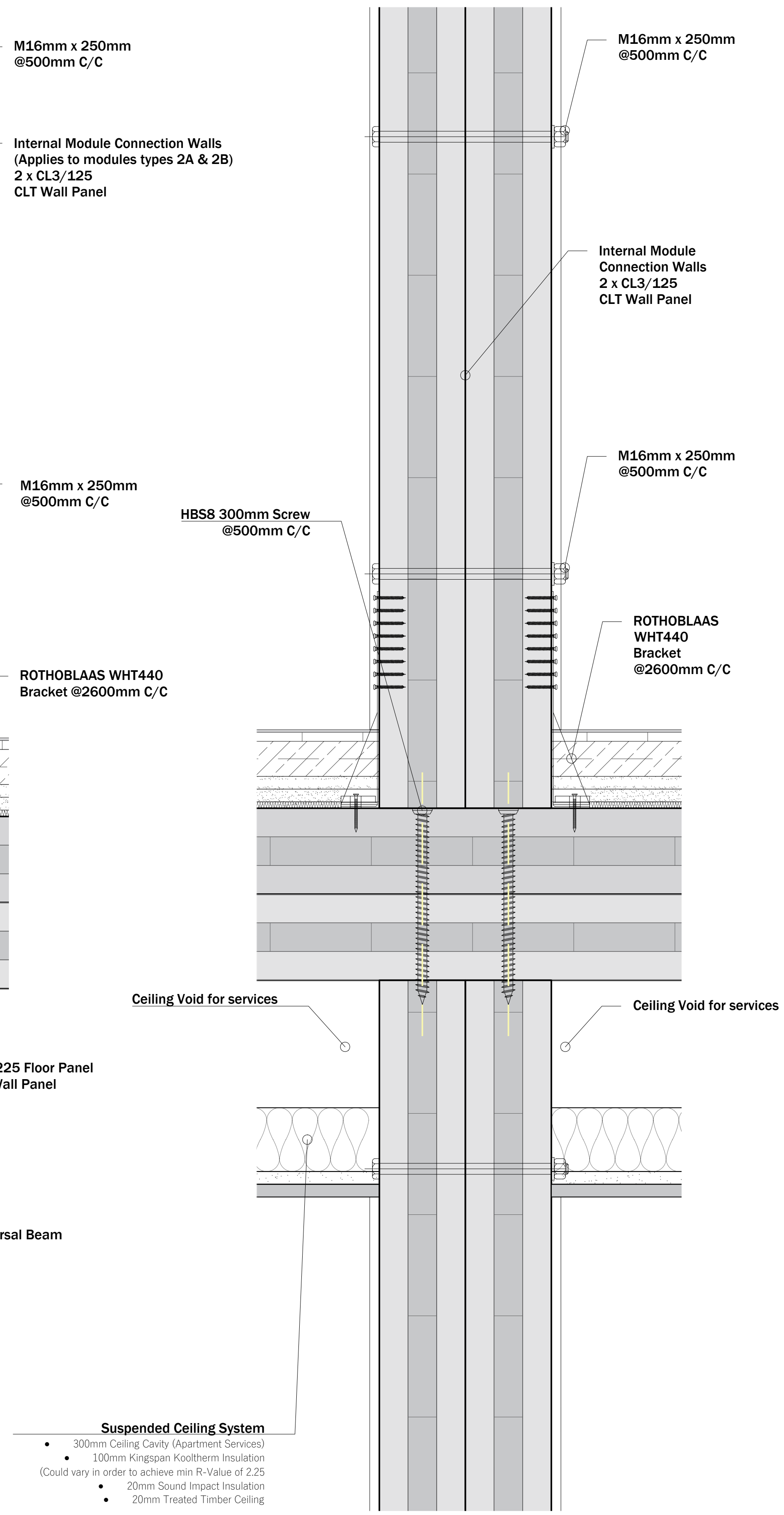
D-11 Module Connection Wall to Ground Floor

SCALE: 1:10



D-12 Module Connection Wall to Wall

SCALE: 1:10



1 2 3 4 10

J F
AO

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

Notes:
1.

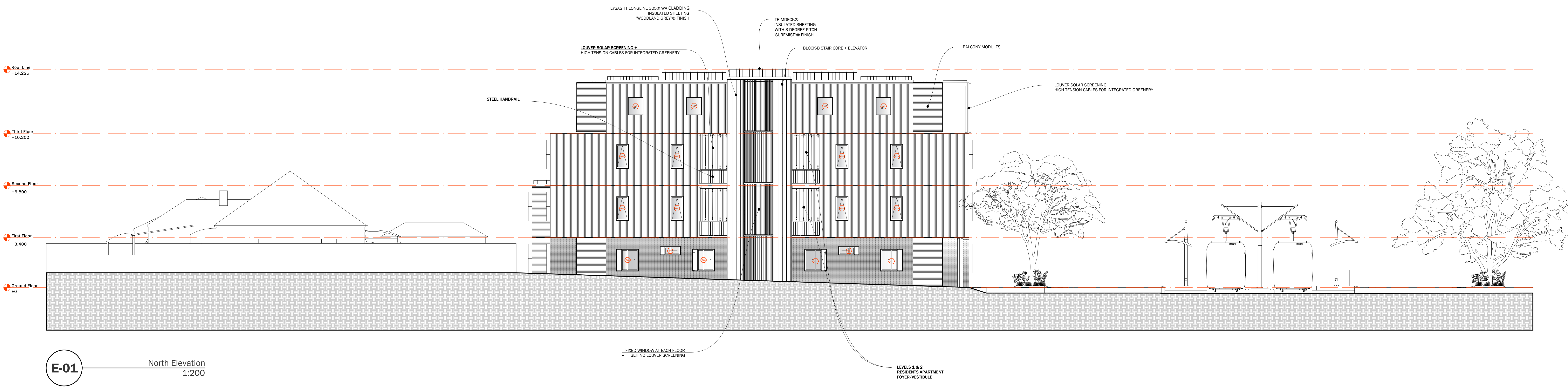
CLT Connection Details (Section View)

Scale: 1:10 @ A3

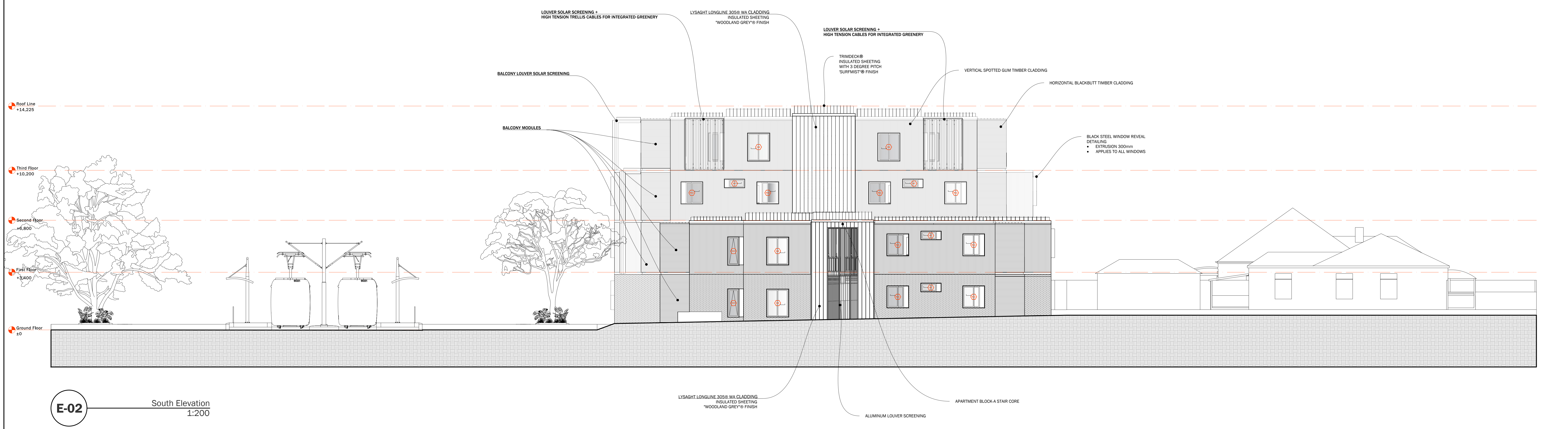
Drawing ID: A-19

Drawn by:

A-19



E-01 North Elevation
1:200



E-02 South Elevation
1:200

1 2 3 4 10

JF
AO

Specifications:

- Vertical timber cladding is to run at the same profile and direction as shown in drawings.
- Vertical timber cladding is to run vertically as shown in drawings to meet flush with roof line to conceal it. Spotted Gum Timber cladding is to be off PROPLANK application, provided by Mortlock Timber.
- All Balcony Modules are to be clad externally with TRENDPLANK option with Blackbutt finish, provided by Mortlock Timber. Same conditions applied to internal decking of Balcony as well.
- All window reveal details as shown in drawing will be 3mm thick steel, extruded to 300mm with an Anthracite finish and is to run flush with window frame edge. These are to be provided by Reliance Design & Fabrication.
- All external timber cladding is to be fixed to wall panel cassette system. Refer to details for more information.
- All external lightweight brick veneer cladding on ground floor modules is to be applied using *clip and rail* system. Brick type is to be "la Paloma" - provided by australbricks.
- All external iron cladding is of LYSAGHT LONGLINE 305® WA profile with "Woodland Grey®" finish.
- Spacing of structural roof trusses are to be specified by Lysaught installation guidelines.
- Sun Louvers will utilize "120mm Flush Panel" provided by LouverTec. This may vary dependant on calculated wind-loads on site. Louver system is to incorporate high tension wire espalier trellis between each louver panel.
- Integrated Box Gutter Systems will incorporate the "Quad Gutter" profile provided by Stratco, refer to details and roof plan for more information.

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 05/04/2020

Notes:
1.

North & South Elevations

Phase:
Construction Documentation

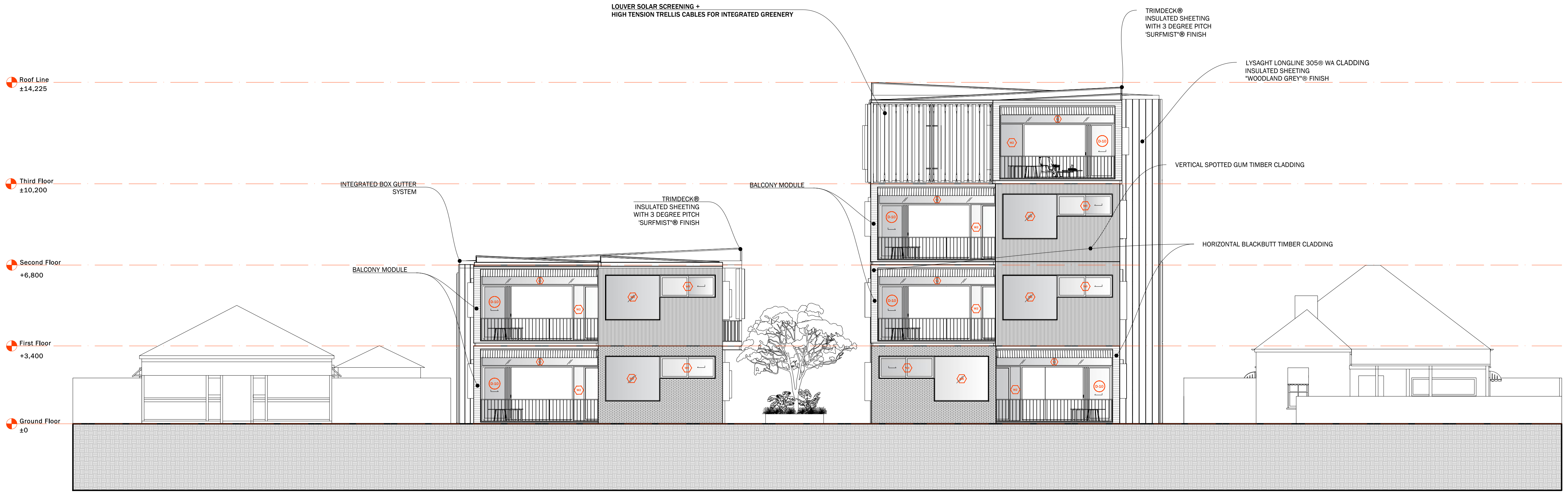
Scale: 1:200 @ A2

Drawing ID: E-01

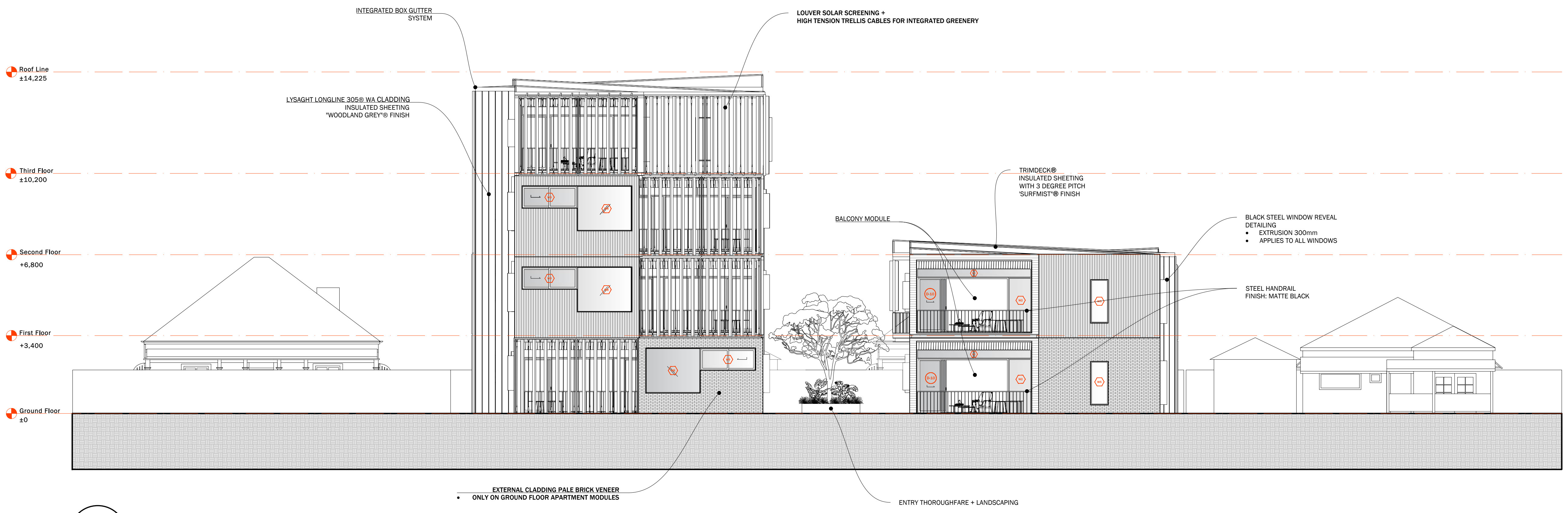
Drawn by:

E-01

J F
AO



E-03 East Elevation 1:200



E-04 West Elevation 1:200

1 2 3 4 10

Specifications:

- Vertical timber cladding is to run as the same profile and direction as shown in drawings.
- Vertical timber cladding is to run vertically as shown in drawings to meet flush with roof line to conceal it. Spotted Gum Timber cladding is to be off PROPLANK application, provided by Mortlock Timber.
- All Balcony Modules are to be clad externally with TRENDPLANK option with Blackbutt finish, provided by Mortlock Timber. Same conditions applied to internal decking of Balcony as well.
- All window reveal details as shown in drawing will be 3mm thick steel, extruded to 300mm with an Anthracite finish and is to run flush with window frame edge. These are to be provided by Reliance Design & Fabrication.
- All external timber cladding is to be fixed to wall panel cassette system. Refer to details for more information.
- All external lightweight brick veneer cladding on ground floor modules is to be applied using *clip and rail* system. Brick type is to be "La Paloma" - provided by australbricks.
- All external iron cladding is of LYSAGHT LONGLINE 305® WA profile with "Woodland Grey®" finish.
- Spacing of structural roof trusses are to be specified by Lysaught installation guidelines.
- Sun Louvers will utilize "120mm Flush Panel" provided by LouverTec. This may vary dependant on calculated wind-loads on site. Louver system is to incorporate high tension wire espalier trellis between each louver panel.
- Integrated Box Gutter Systems will incorporate the "Quad Gutter" profile provided by Stratco, refer to details and roof plan for more information.

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 05/04/2020

Notes:
1.

East & West Elevations

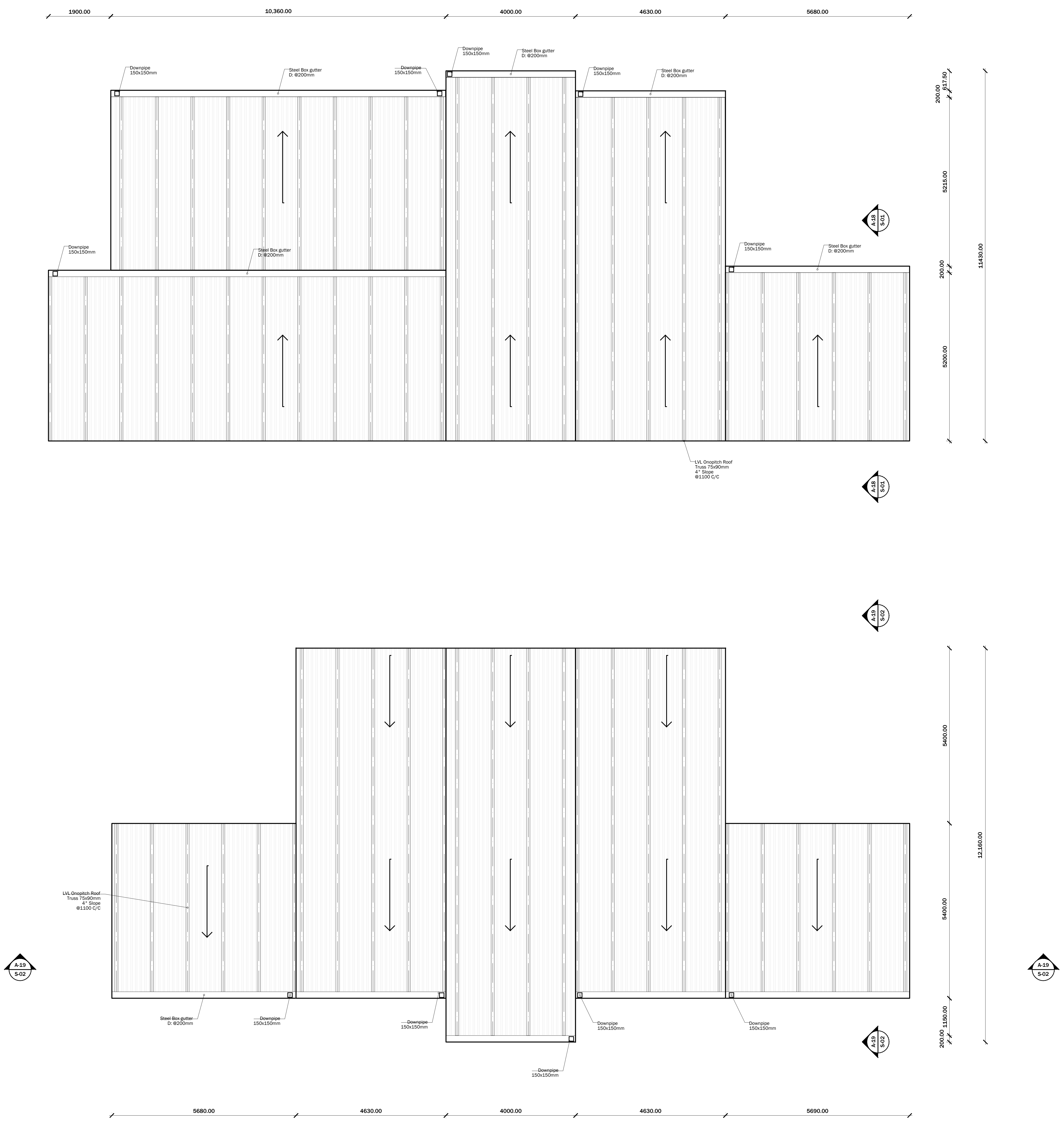
Phase:
Construction Documentation

Scale: 1:200 @ A2

Drawing ID: E-02

Drawn by:

E-02



1 2 3 4 10

JF AO

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 24/03/2020

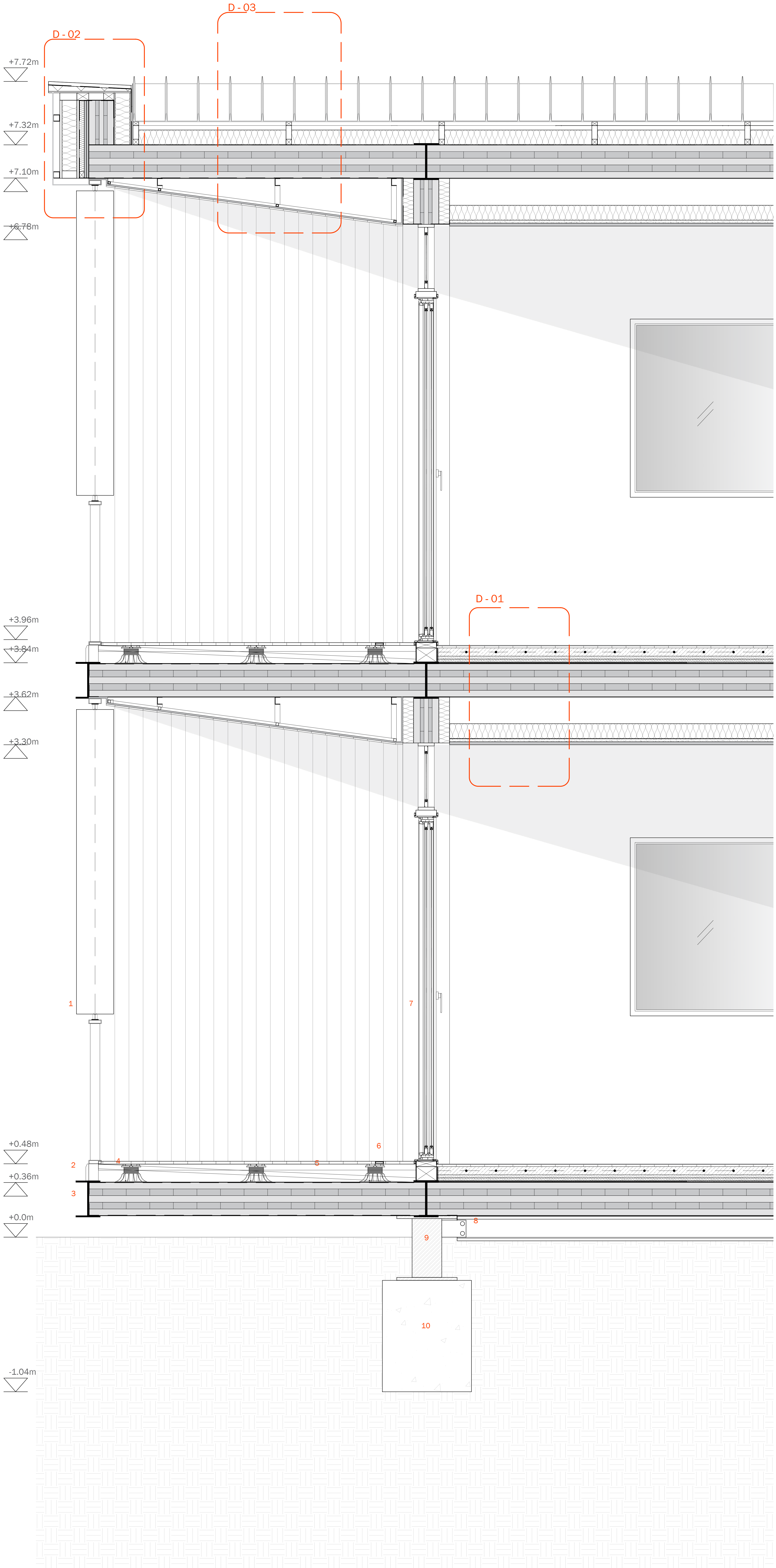
Notes:
1.

Roof Plan
Phase:
Construction Documentation

Scale: 1:100 @ A2
Drawing ID: R-01

Drawn by:

R-01



D - 01

Floor & Ceiling Package

+

- 3mm Protective Floor Coating 15mm
- 15mm (Optional) Hardwood Timber Flooring
- 55mm Cement Screed Flooring with Integrated underfloor heating
- 20mm Sound Impact Insulation
- 20mm Fibre Screen Flooring
- 10mm Regupol® 6010 is a soundproofing acoustic underlay
- 225mm CL5/225 CLT Structural Floor with exposed sofit
- 75x300mm LVL Ceiling Joists
- 300mm Ceiling Cavity (Apartment Services)
- 100mm Kingspan Kooltherm Insulation (Could vary in order to achieve min R-Value of 2.25
- 20mm Sound Impact Insulation
- 20mm Treated Timber Ceiling

\-

D - 02

Parapet Package

+

- Colorbond Steel parapet capping and flashing (to along to box integrated box-gutter)
- Plywood Upstand Cap
- DPM
- Mineral Wool Insulation
- Vapor Barrier
- CL5/145 Structural CLT Wall Panel
- 100mm Rigid Thermal Insulation
- 50x50mm Steel hollow core lintel
- External Steel sheeting to conceal parapet

\-

D - 03

Roof Package

+

- TRIMDECK® Insulated Sheeting with 3 degree pitch 'SURFMIST"® FINISH
- LVL Roof Truss System
- Bradford Anticon Foil-Faced blanket roof insulation
- Integrated gutter down pipe
- 225mm CL5/225 CLT Structural Floor
- Steel C-Channel Support Frame
- Steel Connecting Batterns
- Aluminum sheeting
- Hardwood Timber Cladding to Balcony Ceiling Finish

\-

General Specifications

1. LouverTec "120mm Flush Panel" Sliding Sun Shading Louver
2. Steel Flashing
3. Structural Steel I-Beam
4. Adjustable balcony Pedestal System
5. Larch Board with 4° Slope leading to Drainage Downpipe
6. Balcony Drainage Gully
7. Double Glazed Glass Sliding Door (Refer to Door Schedule)
8. Structural Steel Support Framing
9. Steel Base Plate Connection to Concrete Footing
10. 1200x1200x1500 Prefab Concrete Footing (Or to structural engineers specifications)

1 2 3 4 10

JF
AO

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 21/04/2020

Notes:
1.

Facade Section South View
Apartment Block A

Phase:
Construction Documentation

Scale: 1:20 @ A2

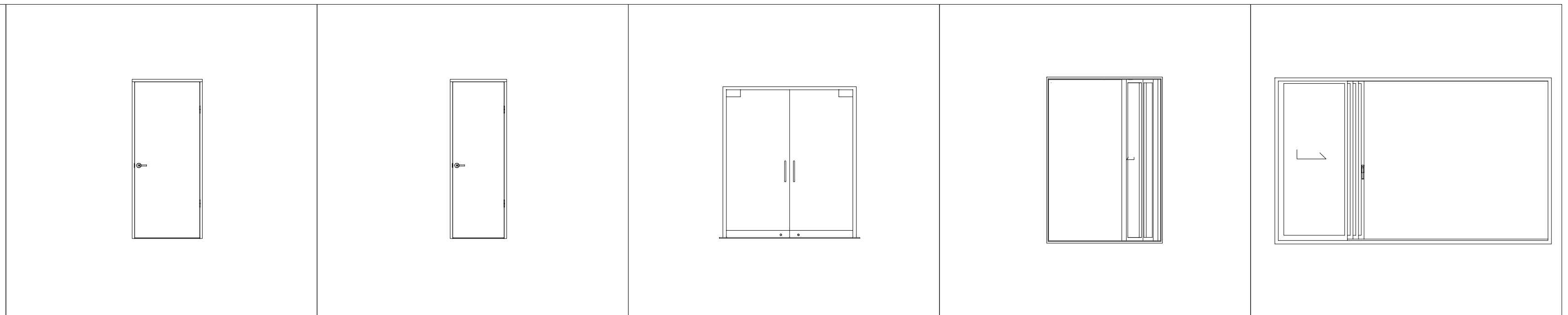
Drawing ID: S-01

Drawn by:

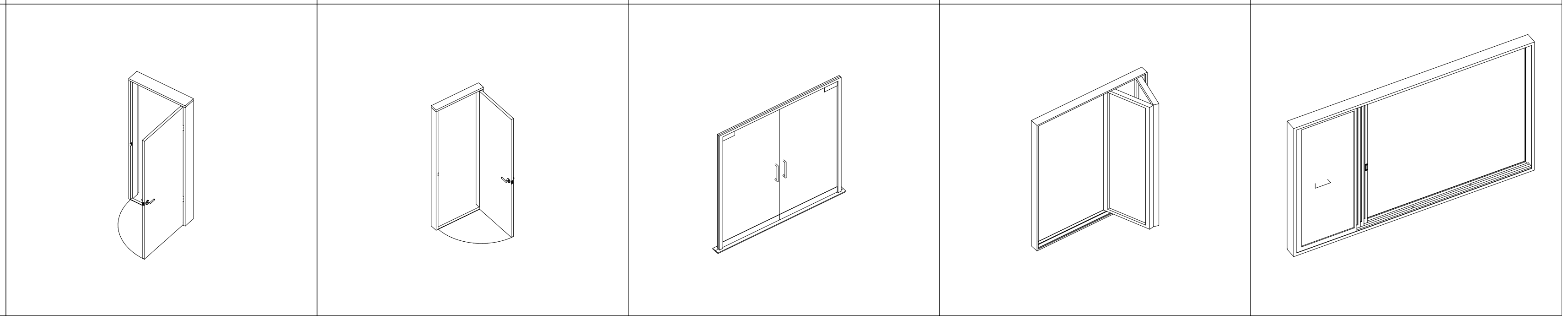
S-01

Name	External Door	Internal Door	Double Swung Commercial Door	External Folding Door	3 Panel Sliding Door
ID	D-01	D-02	D-03	D-04	D-05
W x H	920 x 2100	720 x 2100	1900 x 2100	1680 x 2100	4000 x 2400
Frame Type	Timber	Timber	Aluminum (Matte Black)	Aluminum (Matte Black	Aluminum (Matte Black)
Panel	Fire Proof Solid Core	Primed MDF (Hollow Core)	Glazed Glass	Glazed Glass	Double Glazed Glass
Colour/Finish	White Paint Finish	White Paint Finish	Glazed Glass	Glazed Glass	Double Glazed Glass

View

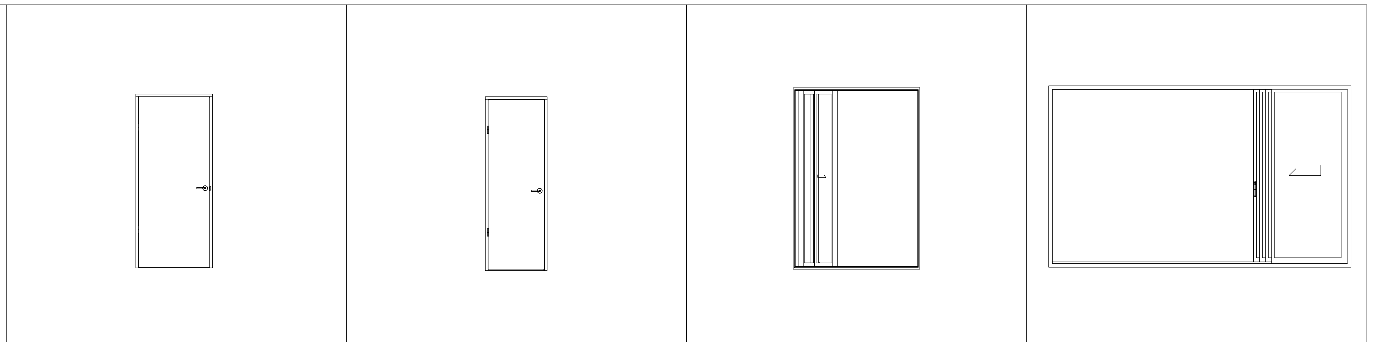


3D Preview

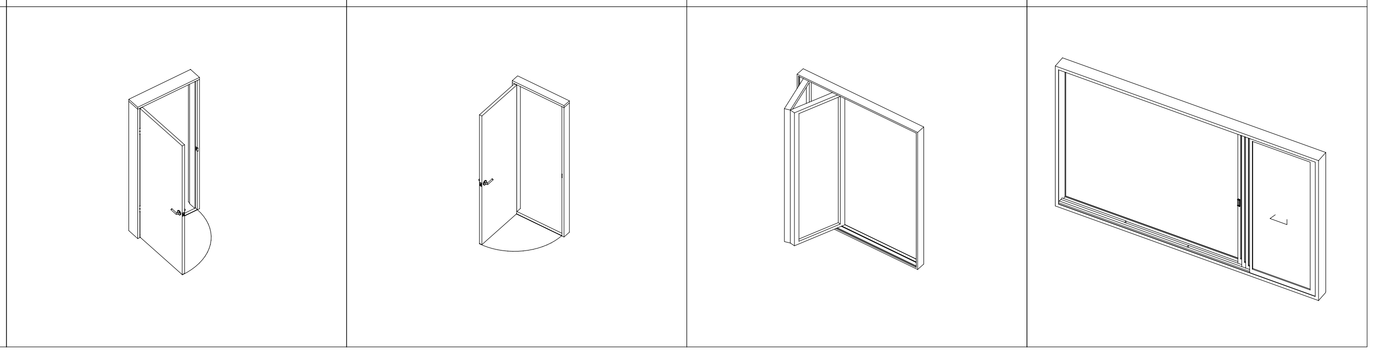


Name	External Door	Internal Door	External Folding Door	3 Panel Sliding Door
ID	D-06	D-07	D-09	D-10
W x H	920 x 2100	720 x 2100	1680 x 2100	4000 x 2400
Frame Type	Timber	Timber	Aluminum (Matte Black	Aluminum (Matte Black)
Panel	Fire Proof Solid Core	Primed MDF (Hollow Core)	Glazed Glass	Double Glazed Glass
Colour/Finish	White Paint Finish	White Paint Finish	Glazed Glass	Double Glazed Glass

View



3D Preview



1 2 3 4 10

JF
AO

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 02/04/2020

Notes:
1.

Door Schedule
Phase:
Construction Documentation

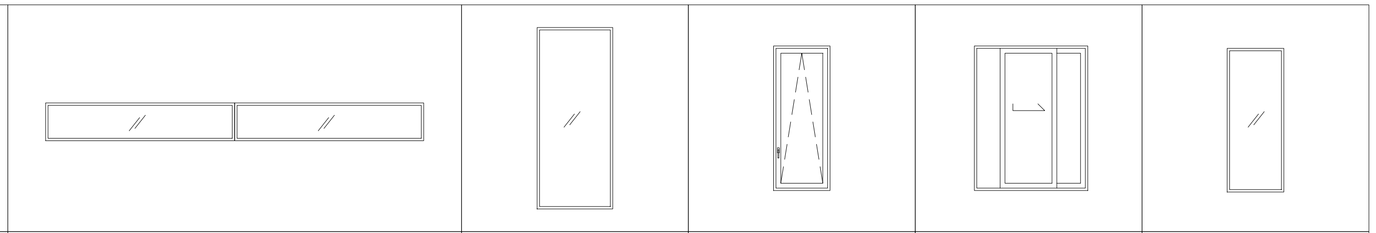
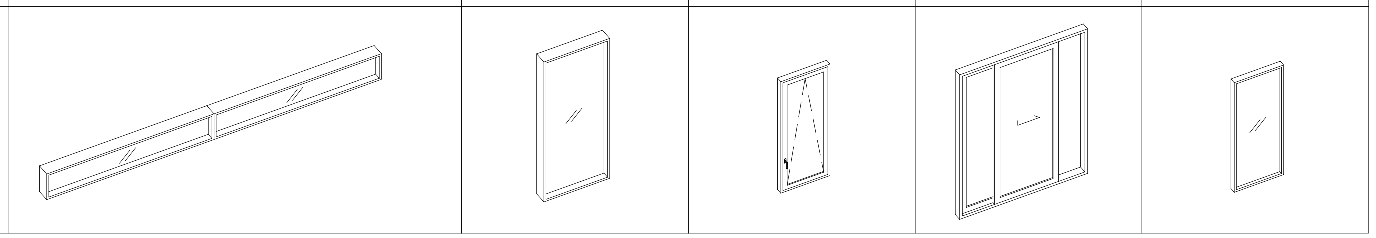
Scale: 1:100 @ A3

Drawing ID: A-10

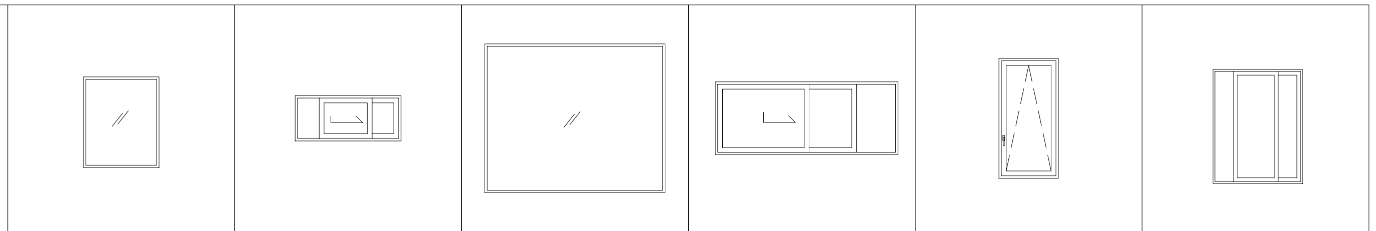
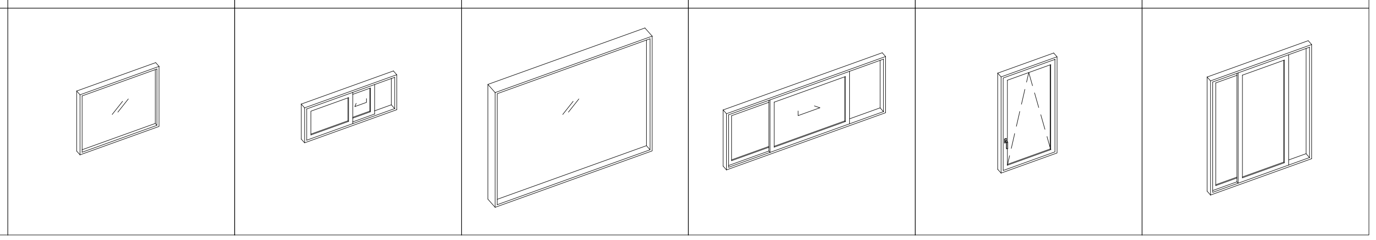
Drawn by:

D-10

Name	2 Sash Fixed Window	Fixed Window 1	Awning Window 1	2 Sash Sliding Window	Fixed Window 2
ID	W1	W2	W3	W4	W5
W x H	5000 x 500	1000 x 2400	750 x 1900	1500 x 1900	750 x 1900
Sill Height	2400	0	475	485	475
Head Height	2900	2400	2415	2400	2415

View	
3D Preview	

Name	Fixed Window 3	2 Sash Sliding Window 2	Fixed Window 4	2 Sash Sliding Window 3	Awning Window 2	Awning Window 2
ID	W6	W7	W8	W9	W10	W11
W x H	1000 x 1200	1400 x 600	2385 x 1970	2415 x 980	850 x 1650	1180 x 1500
Sill Height	1120	2200	990	1975	1030	1030
Head Height	2320	2800	2960	2960	2680	2680

View	
3D Preview	

1 2 3 4 10

JF
AO

Project

3x3haus

Location:
1 Rosebery st, Bayswater

Date: 02/04/2020

Notes:
1.

Window Schedule
Phase:
Construction Documentation

Scale: 1:100 @ A3

Drawing ID: A-11

Drawn by:

A-11

Fleetwood Project

Budget Evaluation

This report submission contains the following for the budget evaluation:

1. Approximate Estimation
2. Preliminary Estimation
   2.1. Key Considerations for the Preliminary Estimation

1 Approximate Estimation

The following previous projects are used to assist in the calculation of the approximate cost:

Project	No. Floor Levels	No. Apartments	Project Cost	Adjustment Factor
Brighton Road Apartments	3	12	$1.85m	1.00
The Marc	4	43	$9.90m	0.20
Grosvenor Street Apartment	3	13	$3.00m	0.90
Orrong Road Apartments	3	10	$2.00m	1.20

Table 1: Previous projects features key features and construction costs

Approximation estimate calculation is performed as shown below:

Project	Adjusted Project Cost	Year	Time Conversion Index Dec 2020	Time Converted Cost	Total Area (m^2)	Rate/m^2
Brighton Road Apartments	$1.85m	2016	1.17	$2,917,965	512	$4,217
The Marc	$1.98m	2016	1.17	$2,311,028	1050	$2,201
Grosvenor Street Apartment	$2.70m	2014	1.22	$3,283,660	752	$4,367
Orrong Road Apartments	$2.40m	2004	1.74	$4,172,904	1207	$3,457
					Average	**$3,561**

Approximation Cost (rate/m^2)	$3,443
Fleetwood Project Area (m^2)	1000
Fleetwood Project Approximate Cost	**$3,443,421**

Table 2: Cost comparison of similar past projects for the year 2020

The approximation rate is calculated using the following formula:

$$Approximate\ Cost = \frac{A + 4B + C}{6} \times Site\ Area = \$3{,}443/m^2$$

Where:

A = minimum rate of previous similar project = $2201/m^2$

B = average rate of previous similar project = $3561/m^2$

C = maximum rate of previous similar project = $4217/m^2$

Site Area = $1000m^2$

This gives the ***Fleetwood Project Approximation Cost = $3.4M***

2 Preliminary Estimate

The preliminary estimate for the Fleetwood Project will include the following elements and sub-elements:

- Preliminaries
- Substructure
  - Site Clearance
  - Earthworks
  - Foundations
- Superstructure
  - Upper Floors
  - Staircase
  - Roof/ Ceiling
  - External Walls
  - Windows
  - External Doors
  - Internal Walls
  - Internal Doors
  - Balcony
  - Lift
- Internal Finishes
  - Walls
  - Floor
  - Ceilings
- Fixtures and fittings
- Services
  - Plumbing
  - Mechanical
  - Fire
  - Electrical
- External works
  - Site Organisation
  - Drainage
  - Minor Works
- Contingency

Budget Evaluation
25/04/20

The overall ***Fleetwood Project Preliminary Cost = $3.9M***

The preliminary cost summary is found in the table 3 along with the percentage breakdown in figure 1. The cost is broken down into the key elements of the project.

Element	Estimated Value	Percentage
Preliminaries	$432,582	12.8%
Substructure	$97,750	2.9%
Superstructure	$1,925,354	57.1%
Internal Finishes	$220,524	6.5%
Fixtures & Fittings	$139,750	4.1%
Services	$490,500	14.5%
External Works	$10,000	0.3%
Contingency	$55,500	1.6%
SUB-TOTAL	**$3,371,960**	**100%**
10% GST	**$337,196**	
OVERHEADS & PROFIT	**$236,037**	
TOTAL	**$3,945,193**	

Table 3: Preliminary cost summary

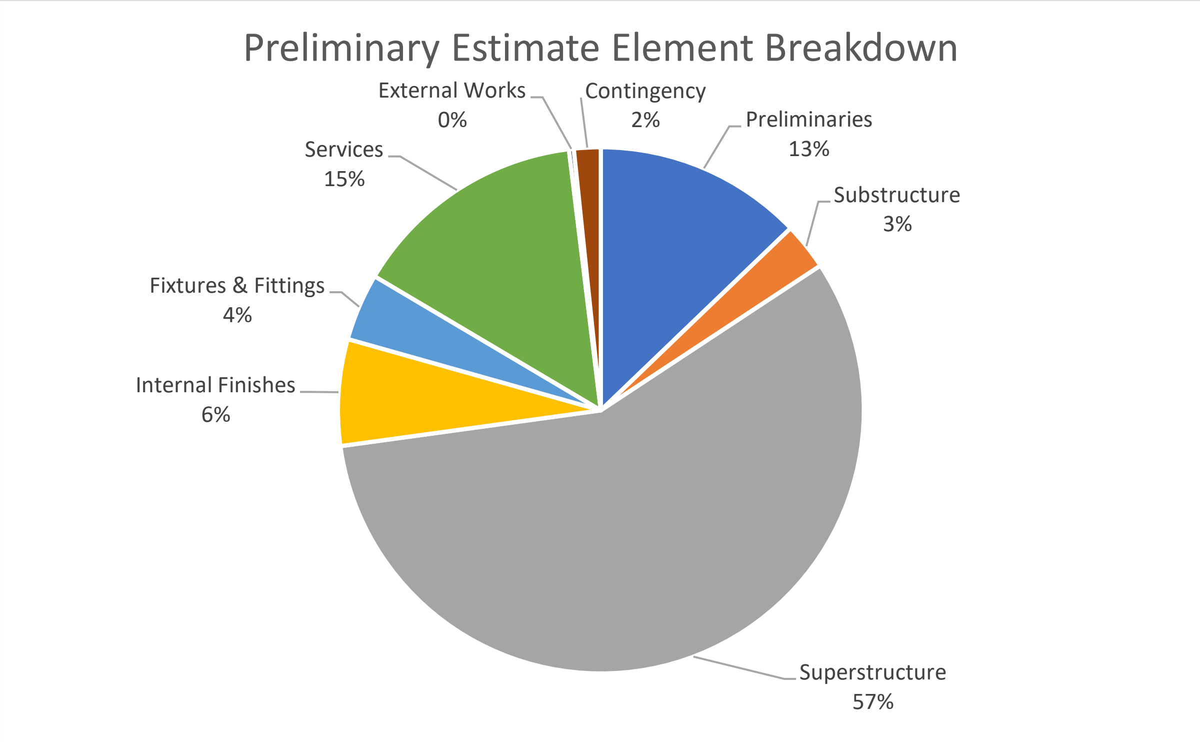


Figure 1: Elemental cost breakdown

Approximation Estimate and the Preliminary Estimate has a price difference of 12.7%. This difference is deemed within acceptable range for pricing.

2.1 Key Considerations for the Preliminary Estimation

i. Superstructure

"Window and door elements a design specifically for the Fleetwood Project therefore these size ranges are not found in construction cost guides. These price rates are determined by taking the face area of the door or window designed by the Architect and selecting a rate from the construction guides with a similar area."

"The walls square meter quantities are determined using the height of the walls as 3.4m."

"Glasswool insulation was used in the pricing as an alternative to woodfibre insulation due to the significantly high difference in price rates"

ii. Internal Finishes

"The plasterboard for the internal walls and ceiling is priced with a fire-rated material has is used to consider for fire design and protection of the CLT panels."

iii. Fixtures & Fittings

"The fixtures for the modular buildings consider all fixed wardrobes, kitchen units, bathroom suites, plugs and sockets that are present in the apartment designs identified in the Architects plan view drawings. Fittings such as curtain rails, mirrors and aerial tv/satellite dishes are also considered for pricing."

iv. Services

"Services considered for pricing include the installation and delivery of plumbing, fire, mechanical and electrical works for the modular buildings."

v. Preliminaries

Preliminaries are any in-direct cost involved during the construction works. An allowance for **15%** of the direct costs makes up **$432,582** for these preliminaries.

vi. Contingency

"Due to unforeseen events that could occur during construction, contingency costs are included in the Fleetwood Project estimation. Contingencies on the project make up **$55,500** of the estimation which is considered acceptable given the size and complexity of the project."

i. Overheads & Profits

"An allowance of 7% for overheads and profits has been added to the preliminary estimate."

Design Calculation Summary

The following is a summary of results proving the validity of the CLT modular design. For full detailed calculations refer to the detailed design calculations report. This report is intended to be a fully comprehensive document detailing the significant findings of the detailed calculations report.

Floor Design Vertical Loading

The Floor is subject to vertical gravity loads and lateral loads caused from wind and earthquake actions. A CL5/225 panel was chosen as the floor and ceiling panel of the modular buildings. The size was chosen in consideration of the manufacturers (Xlam) span charts and Wood Solutions design guide 46 appropriate span to depth ratio of 25. Since the maximum span of the panel is 5.4m, 5400/25 ≈ 225mm.

The maximum Vertical pressure on a floor panel is:

G=4.6kPa - Ceiling + Floor of the level above + 2 x SDL

and

Q=1.5kPa - AS/NZS 1170.1 Table 3.1, A

Floors must be designed to satisfy three performance criteria's:

- Deflection Performance
- Dynamic Performance
- Strength Performance
    - Bending Capacity
    - Shear Capacity

Deflection Performance

Deflection Performance Checks that L/ Δ > 300.

Deflection is a serviceability limit state and therefore subject to load case G = 4.6kpa.

Δmax (mm) = 9.62mm

L/ Δ = 561 > 300 therefore Ok

Dynamic Performance

Dynamic Performance checks the deflection of the floor under a 1KN force does not exceed 1.5mm, the dynamic frequency is no less than 8Hz and that the acceleration criteria is greater than 13.

Δ_{1KN} = 0.31mm <1.5mm ∴ok

F1 = 16Hz > 8Hz ∴ok

37 > 13 ∴ok

Strength Performance – Bending & Shear Capacity

The bending strength is determined considering ultimate limit state action. The bending capacity of the floor must be greater than the applied action ϕM > M*.

Load Case 3 was found to be the most critical condition giving the load combination factor of:

- 1.2G + 1.5ψlQ
- Meaning W* = 7.77kPa

M* (KNm) = 23.40

ϕM (KNm) = 79.84

ϕM > M* ∴ CL5/225 satisfies the Bending Strength criteria.

The shear strength is determined considering ultimate limit state action. The shear capacity of the floor must be greater than the applied action ϕV > V*.

V* (KN) = 17.33

ϕVL (KN) = 574.99

ϕVR (KN) = 795.97

ϕV > N* ∴ CL5/225 satisfies the Shear Strength criteria.

Floor Design Lateral Loading

Both Wind and Earthquake actions were calculated in consideration of the lateral loading with earthquake being the most significant.

W*(KN/m) = 16.54 Line Load

V* (KN) = 89.34 Earthquake Action

M* (KNm) = 241.21 Earthquake Action

φM (KNm) = 1071 Bending Capacity

φM > M* ∴ CL5/225 satisfies the Bending Strength criteria.

φfs (MPa) = 0.96 Shear Capacity along joints

$\tau_{0,90}$(MPa) = 0.367E-3 Shear stress along joints

τ_{TD}(MPa) = 0.074 Torsional Shear Strength

φfs > $\tau_{0,90}$ ∴ CL5/225 satisfies the Shear Stress along joints

φfs > τ_{TD} ∴ CL5/225 satisfies the Torsional Shear Capacity

Wall Design Vertical Loading

From axial gravity loads applied to a wall, it is susceptible to Compressive failure, bending failure due to eccentricity, bearing failure, combined actions failure and excessive wall shortening and differential deflections. A CL3/125 CLT panel was chosen when considering the Xlam manufactures design guide Table 12. A 125mm thick panel was chosen as an estimated reduction of it's capacity by 20% still yielded enough strength to support the estimated loading of 200KN/m.

The most critical Vertical loading on a wall panel was determined from load case 3 to be:

- P_G = 52.10 KN/m and 50.40 KN
- P_Q = 16.90 KN/m and 21.87 KN

Axial Compressive Capacity

The Axial Capacity for Compressive design loads must satisfy φNc > N*.

φNc (KN/m) = 72.66

φNc > N* ∴ CL3/125 satisfies the Compressive Strength criteria.

Axial Bending Capacity (Eccentricity)

Calculate the panels Bending Capacity for potential eccentric loading conditions. The Bending Capacity for eccentric design loads must satisfy φM > M*.

M* = N x et

Where et is the position of eccentric loading = tp/15 = 8.33mm

M* (KNm) = 0.61

φM (KNm) = 17.28

φM > M* ∴ CL3/125 satisfies the Bending Strength criteria.

Combined Action check (Compression and Bending)

Combined bending and compression members shall be proportioned to satisfy the follow equations.

$$\text{Check 1} = \left(\frac{M*}{\phi \text{Mb}}\right)^2 + \frac{N*}{\phi Nc} \leq 1$$

and

$$\text{Check 2} = \left(\frac{M*}{\phi \text{Mb}}\right) + \frac{N*}{\phi Nc} \leq 1$$

Check 1 = 0.3 < 1

Check 2 = 0.33 < 1

Bearing Capacity check

Calculate loaded cross-sectional area of elements, perpendicular to grain in story. Perpendicular to grain crushing is a strength test, but as the wood crushes, it still transmits loads of bearings and seldom causes any collapse. As the crushing continues, the structure deforms, so bearing perpendicular to grain is pragmatically a matter of serviceability rather than a matter of energy. This must also be measured as a strength test to ensure conformity with AS 1720.1.

φNb = φb*k1*k4*k6*k7*f'p*Api

φNb (KN) = 963.87

N* (KN) = 74.4

φNb > N* ∴ CL3/125 &CL5/225 satisfies the Bearing Strength criteria.

Vertical Wall Settlements

Axial shortening of a building is a long-term problem. Therefore, all loads considered in the estimation of shortening are long-term gravity loads. It is a serviceability issue and uses a load combination *G*.

In the case of this 4-story apartment building, settlement was calculated for the critical 3 walls at every level with the highest two walls being compared against eachother.

The total settlement per level is equal to $\delta t = \delta_{s,l} + \delta_{s,p} + \delta_{c,l} + \delta_{c,p} + \delta_j$

This is an addition of:

- Shrinkage parallel and perpendicular to grain;
  - $\delta_{s,l} = up*\Delta mc*L$
  - $\delta_{s,p} = up*\Delta mc*d_p$
- deformation and creep parallel and perpendicular to grain;
  - $\delta c,l = \sum_{floors} \frac{j_2 \ N_{c,i} L_i}{E_i A_{p,i}}$
  - $\delta c,p = \sum_{floors} \frac{j_2 \ N_{c,i} \ d_{2,i}}{E_i A_{p,i}}$
- settlement of the joints
  - $\delta_j = n_{joints} * \delta_{gaps}$

The total and differential settlement is shown in the table below.

	Differential Settlement			
	Wall 1 δtotal (mm)	Wall 2 δtotal (mm)	Wall 3 δtotal (mm)	ΔδMax
Third Level	5.64	4.99	5.01	0.65
Second Level	8.33	9.00	7.36	1.63
First Level	9.61	11.53	8.61	2.92
Ground Level	10.88	14.07	9.89	4.18

Table 1: Total Settlement of each wall and highest differential settlement

Wall Design Lateral Loading

Walls are subjected to wind and earthquake actions with the larger being the case considered for lateral design.

Relative Stiffness and Centre of Stiffness

Before you can calculate how the design actions affect an individual element, the stiffness of each element and the stiffness of the element with reference to the entire structure must be carried out in order to asses what percentage of the applied load acts on the elements.

Wall Length (mm)	K (N/mm)
12000	44690.51
10400	40427.11
6000	24424.63
5400	18933.38
4400	12813.24
4000	11603.40

Table 2: Stiffness for each wall panel

As each floor has a different configuration, table 3 shows the different floor stiffness for x and y direction walls.

Level 3 Kx (N/mm)	**Level 3 Ky (N/mm)**	**Level 2 Kx (N/mm)**	**Level 2 Ky (N/mm)**	**Level 2 Kx (N/mm)**	**Level 2 Ky (N/mm)**	**Level 1 Kx (N/mm)**	**Level 1 Ky (N/mm)**	**Ground Kx (N/mm)**	**Ground Ky (N/mm)**
178536.76	208102.02	346623.70	202981.33	346623.70	202981.33	346623.70	202981.33	346623.70	202981.33

Table 3: Total floor stiffness in the x and y direction

Wind & Earthquake Loading

From a thorough analysis of the different load cases, the table below is the finding of the most critical wind actions in the x and y direction applied at each floor level.

Floor	A_x m^2	A_y m^2	F_x (kN)	F_y (kN)	F_x CUM	F_y CUM
R	5.79	13.42	5.79	13.42	4.58	10.61
3	41.96	97.1	41.96	97.10	33.18	76.78
2	41.96	97.1	41.96	97.10	33.18	76.78
1	41.96	97.1	41.96	97.10	33.18	76.78
G	41.96	97.1	41.96	97.10	33.18	76.78

Table 4: Cumulative Wind loading on each floor

Vertical distribution of forces	Force (kN)	Cumulative Force (kN)
1	42.43	407.47
2	82.06	365.04
3	121.68	282.98
R	161.30	161.30

Table 5: Cumulative Earthquake loading on each floor

From comparing the tables above it is clear that the earthquake loading is the critical condition in this case.

The critical shear and moment acting on a single wall was then found to be acting on the staircase and lift shaft walls but was taken to be the highest action the modules will be designed to, nevertheless.

V^*= 88.84 kN

M^*= 898.98 kNm

Shear Wall Bending and Shear Capacity

The bending and shear capacity must be checked for the modular walls and shall satisfy $\phi M > M^*$ and $\varphi fs > \tau_{0,90}$ and $\varphi fs > \tau_{TD}$.

ϕM (KNm) = 2063.46

M^* (kNm) = 898.98

$\varphi M > M^*$ ∴ CL3/125 satisfies the Bending Strength criteria.

The shear capacity along joints from the glue lamination φfs (MPa) = 0.96

The applied shear force creates shearing off failure stress $\tau_{0,90}$ along the CLT Joints.

$\tau_{0,90}$ (MPa) = 0.000189

$\varphi fs > \tau_{0,90}$ ∴ CL3/125 satisfies the Shear Stress along joints

The applied moment creates internal torsional stress along the CLT Joints.

τ_{TD} (MPa) = 0.67

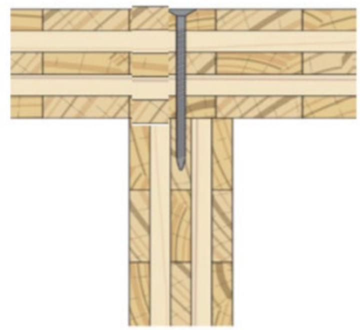
$\varphi fs > \tau_{TD}$ ∴ CL3/125 satisfies the Torsional Shear Capacity

Connections

Screw Design – Withdrawal

Following (Spax EC5 V09.2015) design guide Withdrawal resistance is determined by:

1. Withdrawal failure of thread in wall member
2. Head pull-through failure in floor member
3. Tensile failure of steel



Use Spax Fastener nom diameter 8mm Countersunk head with washer with a penetration depth of 200mm.

Withdrawal Failure						
neff	fax,k (N/mm2)	d1 (mm)	leff (mm)	p (kg/m3)	ϕ	fax,rk (KN)
1	12	8	200	465	0	20.08

Table 6: Capacity of single fastener withdrawal Failure

Head Pull Through Failure				
neff	p (kg/m3)	dh (mm)	fhead,k (N/mm2)	fax,rk (KN)
1	465	20	14	7.03

Table 7: Capacity of single fastener head pull through Failure

Screw Design – Shear Failure

The characteristic value of shear resistance to Eurocode 5 of a connection with SPAX fasteners is determined by comparison of 6 failure modes:

Failure mode (KN)						
a) Fv,Rk,a (KN)	b) Fv,Rk,b (KN)	c) Fv,Rk,c (KN)	d) Fv,Rk,d (KN)	e) Fv,Rk,e (KN)	f) Fv,Rk,f (KN)	Critical Shear Failure (KN)
36.78	11.31	16.16	13.26	3.01	3.87	3.01

Table 8: Results from the six shear failure modes

Design capacity in accordance with AS1720.1

Rdj = φ*k1*k13*k14*k17*n*Qk

Rdj (KN)	V* (KN)	Wall Length	V*/m	Minimum Spacing (m)	Adopted Spacing (mm)
4.58337	88.84	10.4	9.00	1.16	500

Table 9: Fastener Shear Capacity and minimum spacing in accordance with AS1720.1

Bracket Design – Shear Failure

φNdj = φ*k1*k13*k14*n*Qk

φ = 0.8

k1 = 1.14

k13 = 1

k14 = 1

Qk = 70KN - From connection manufacturer

(Rotho Titan TTF 200 selected)

Table : Fastener Shear Capacity and number of brackets.

2 Connections @ 5.2m minimum spacing required.

Bracket Design – Tension Failure

φNdj = φ*Qk

φ = 0.8

Qk = 31.4KN - From connection manufacturer

(Rotho Titan WHT 340 selected)

φNdj = 25.12 KN/connection

V* = 88.84KN

Therefore 4 Connections @ 2.6m minimum spacing required.

MATERIAL RESEARCH

+ Structural Wall System (XLAM CLT Panels)

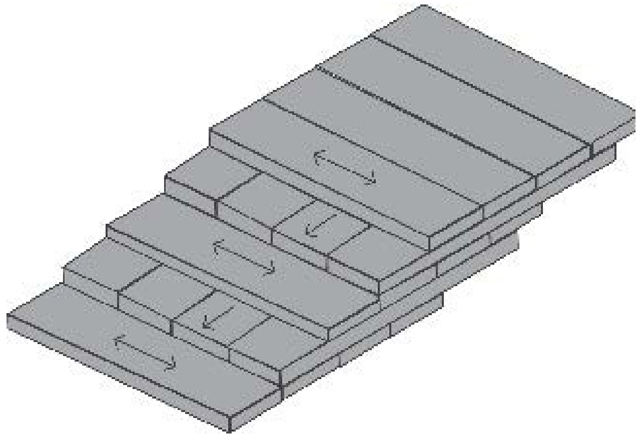
+ Material Information

Company/Manufacturer: *XLAM*

CLT provides a healthy and comfortable indoor climate and is a sustainable choice for building materials with a low carbon footprint and durability. Some of the many advantages of CLT as a natural material is that it works as a stabilizer of humidity, acoustics and temperature, which creates indoor conditions that feel friendly and comfortable to live in.

Through off-site prefabrication methods, CLT can be manufactured to a higher level of accuracy which can ensure minimal defect in the finalised product. Procurement, construction assembly and delivery timescales can also be improved because of this, which results in an overall cost decrease. The inherent structural qualities and the materials ability to allows for airtightness make it a viable choice for multi-residential construction. The most major sustainable benefits from this building material is its carbon sequestration and minimal energy intensive production process allowing it to both store greater amount of CO2 compared to standard concrete construction.

https://www.xlam.co.nz/solutions.html#xlam-clt



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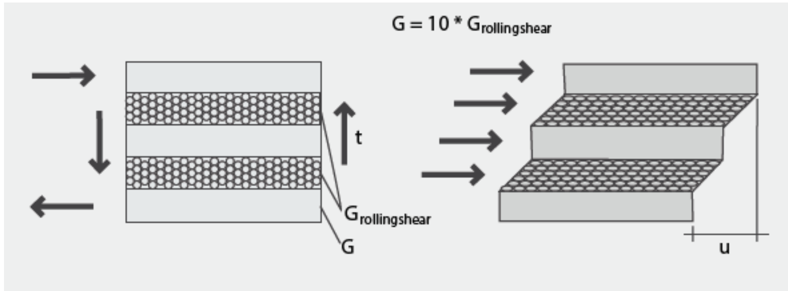


https://www.xlam.co.nz/solutions.html#xlam-clt

MATERIAL RESEARCH

+ Wall Panel System (Digital Wall Cassettes)

+ Material Information

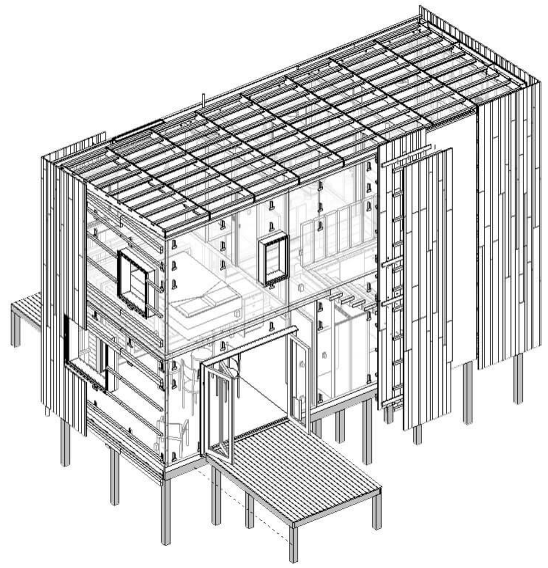
This Architectural Practice in New Zealand designed a unique solution to external cladding systems that work in conjunction with the build nature of CLT construction. Utilizes CNC machinery the cassette system is formulated by parametric calculations that allow the panels to be adapt in shape to allow for the location of services and window/door openings. The cassette panels can be easily demounted from the CLT wall allowing ease of access to attend to the necessary services. This system opens up an array of cladding possibilities, allowing each module to have its own sense of personality through external finishes. The simplicity in the cassette fabrication process allows for easier assembly which reduces the cost for skilled labour, and could potentially allow for clients to become more actively involved in the design and construction process.

Once assembly is complete, each individual cassette is a placed into a set of corresponding routed notches within the CLT wall panels. Through screw fixing methods and frictional jointing for the assembly of the cassettes, it allows for a flexible design system that can be easily unclipped disassembled, altered, moved , reconstructed and even recycled.

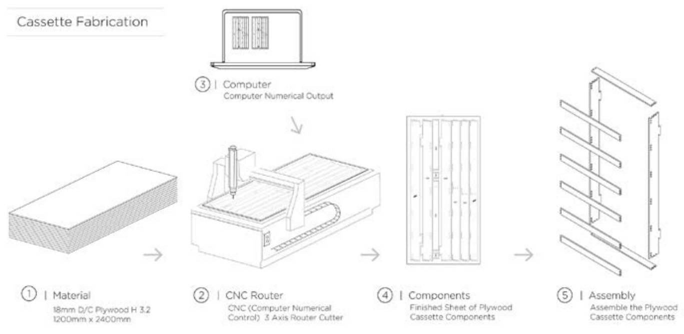
The adaptable nature of the system supports flexible design options and sustainable practices through;

- CNC fabrication techniques which enforces a low-waste system due to optomising material calculations and outputs.
- The ability to recycle the timber used for the cassettes.
- Cost-effective customization which is more precise than traditional timber construction methods.

https://architecturenow.co.nz/articles/building-in-the-digital-age/?utm_source=ArchitectureNow&utm_campaign=c48d041e7b-ArchitectureNow_41_10_July_2013&utm_medium=email&utm_term=0_7c089cf901-c48d041e7b-74396185#img=2



http://www.makersofarchitecture.co.nz/project/warrander-studio



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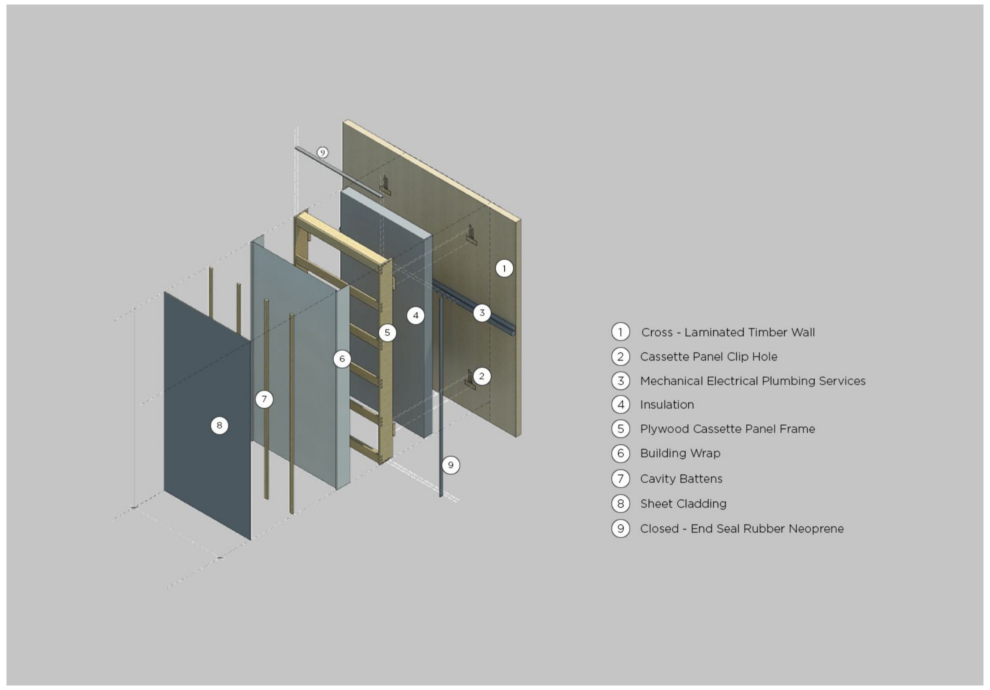

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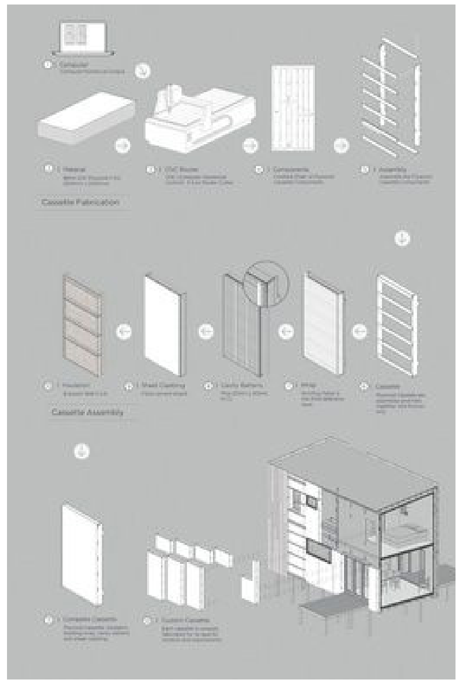


https://architecturenow.co.nz/articles/building-in-the-digital-age/?utm_source=ArchitectureNow&utm_campaign=c48d041e7b-ArchitectureNow_41_10_July_2013&utm_medium=email&utm_term=0_7c089cf901-c48d041e7b-74396185#img=2

MATERIAL RESEARCH

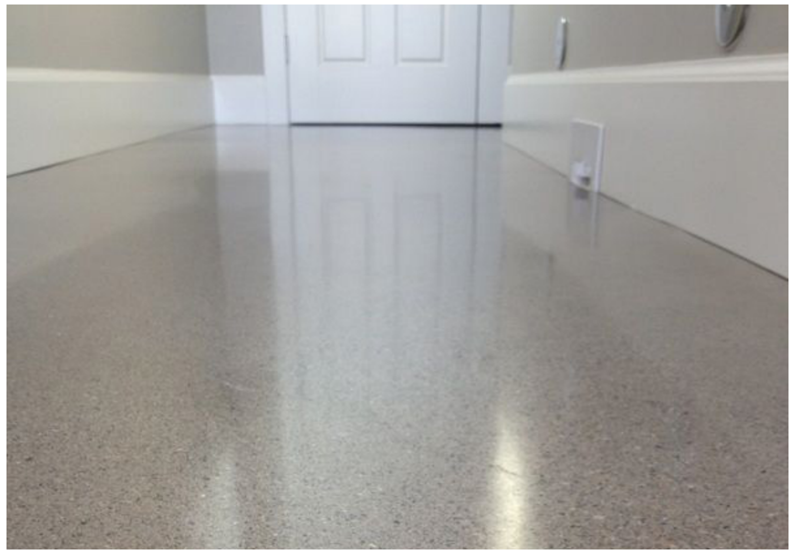
+ Internal Flooring (Option)
- Soundproofed Screed Rubber Flooring

+ Material Information

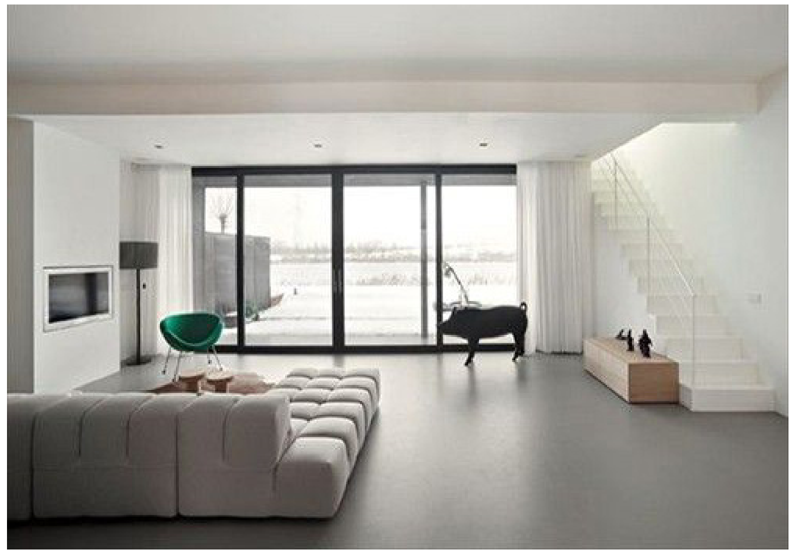
Company/Manufacturer: *ABS West*

Regupol® utilizes recycled rubber it in the manufacturing process of rubber flooring and acoustic underlays. The Regupol® Impact Sound Acoustic Underlays has been certified by Good Environmental Choice Australia (GECA) as a suitable product that contributes to the production of environmental aware building design.

https://www.abswest.com.au/index.php/products/flooring-and-underlay/acoustic-underlay/



http://www.cgppolishedconcrete.com.au/level-of-exposure/



http://resinflooring.co.uk/poured.php

https://www.spectrumfloors.com.au/screed/

https://www.systemfloors.nl/afwerkvloer/troffelvloer/

MATERIAL RESEARCH

+ CORIUM* Mechanical Brick 'Clip & Rail' System

+ Material Information

Company/Manufacturer: *PGH Bricks & Pavers*

The CORIUM system can allow for flexibility in external cladding options with a range of differing profiles, textures and sizes. The system ensure for an improved design flow with seamless transitions around corners, angled surafcae and curvatures that a standard full brick is unable to achieve.

The system is designed so that each brick acts as a tile that can mechanically clip into position. The speed of the installation process for the system is mainly due to less reliance on structural steel elements, providing econmoic value to the porject. This system allows for electrical and water services to run more easily behind the brickwork.

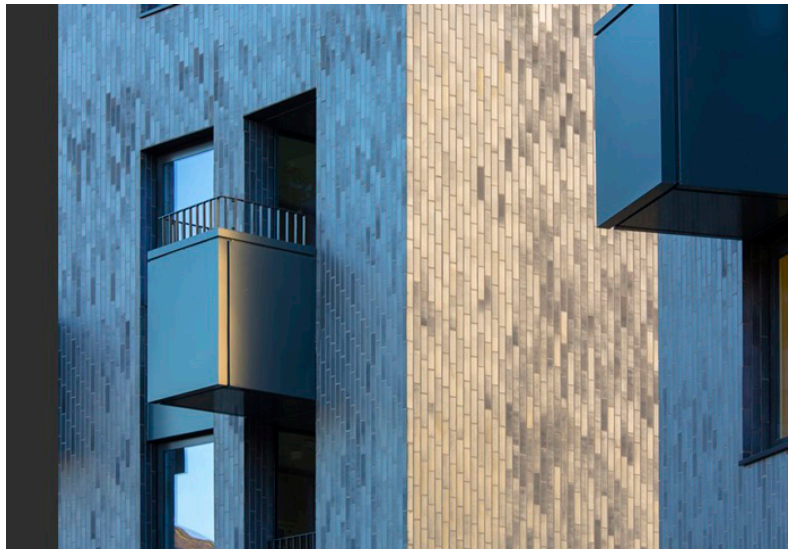
Strong and durable

- Anticipated design life of 60 years in most applications
- Uses HPS200 galvanised steel, or Grade 304 stainless steel backing section (stainless steel below the DPC and in exposure areas)
- Fast and simple installation
- Considerably faster than traditional brickwork to install
- Speeds up the construction process
- Reduced construction costs

Cost-effective and certified

- Suitable for use with a wide range of substructures, including concrete, timber-frame, structural steel, lightweight steel frames, masonry and structurally insulated panels
- Lightweight - buildings may benefit from simpler, lower cost foundations
- Supply and fix solution through PGH Bricks & Pavers' network of recognised installers

https://www.pghbricks.com.au/coriumhomepage/what-is-corium



https://www.pghbricks.com.au/brick-facade-systems

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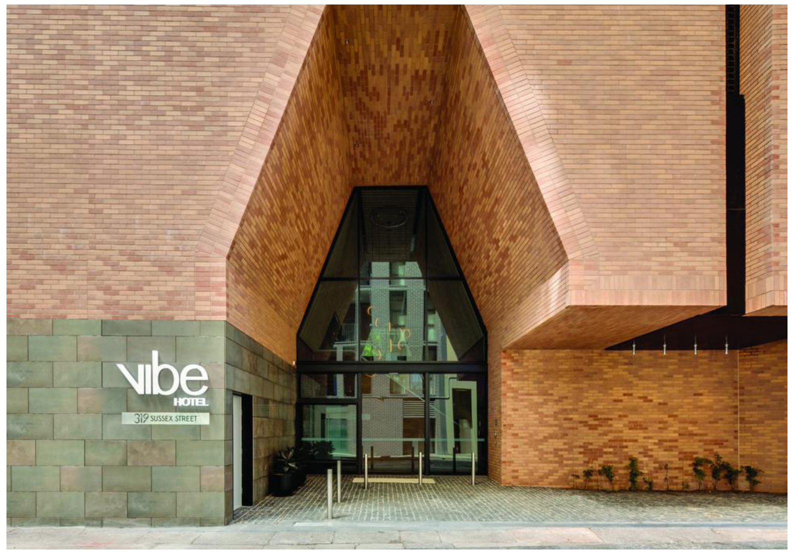


https://www.pghbricks.com.au/brick-facade-systems

Life-Cycle Costing

Draft Example: Apartment Modules + Stair Core CLT Superstructure (Floors and Walls)

	Unit	Quantity	Rate	Inflation Multiplier	Adjusted rate	Total
CLT Wall Panel CL3 125mm, Fire Resistant Lining External & Internal + Waterproofing	m²	1602.02	$216.00	1.05	$226.80	$363,347.21
CLT Floor Panel CL5 225mm	m²	1649.80	$282.00	1.05	$296.10	$488,505.78
CLT Interior Lift and Stair Shaft CL3 105mm	m²	244.20	$206.00	1.05	$216.30	$48,494.46

The CL3 125mm CLT Wall Panel with fire resistant lining external + internal waterproofing has an average cost per m² of $226.80 and has an expected lifespan of 60 years, though this is dependat on varying factors susch as use, maintencance, overall thickness and quality of waterproofing. The total design costs for the superstructure CLT external wall panels of the combined 12 modules is $363,347.21 which means that across the materials expected lifespan, it would cost $6,055.78 per year.

The CL5 225mm CLT Ceiling Panel has an average cost per m² of $296.10 and has an expected lifespan of 60 years, though this is dependat on varying factors susch as use, maintencance, overall thickness and quality of waterproofing. The total design costs for the superstructure CLT internal wall panels of the combined 12 modules is $488,505.78 which means that across the materials expected lifespan, it would cost $8,141.76 per year.

The CL5 225mm CLT Ceiling Panel has an average cost per m² of $216.30 and has an expected lifespan of 60 years, though this is dependat on varying factors such as use, maintencance, overall thickness and quality of waterproofing. The total design costs for the superstructure CLT interior lift shaft wall panels of the combined 2 stair cores of apartment Block A & Block B, is $48,494.46 which means that across the materials expected lifespan, it would cost $808.24 per year.

Total Combined

$900,347.45

Though the conclusive figures show that the yearly pay back of the design CLT superstructure lifespan is relatively costly, there are a number of benefits making it a positive and viable construction option. These benefits include;

- Design Flexibility - allowing for variances in thickness, span and sheet sizes
- Low U-Values emedded in the material make it a thermal performer and more energy efficent thus reducing energy costs for occupants.
- Construction/assembly process is 15% faster than that of concrete or steel construction, particularly with mid-rise residential buildings.
- Minimised job-site wastage through controlled off-site manufacturing
- Seismic Performance - strong lateral load resisitance
- adequate noise control for both airborne and impact sound transmission.

Total Payback per year across 60 year lifespan

$15,005.79

https://www.woodworks.org/wp-content/uploads/CLT-Solid-Advantages.pdf

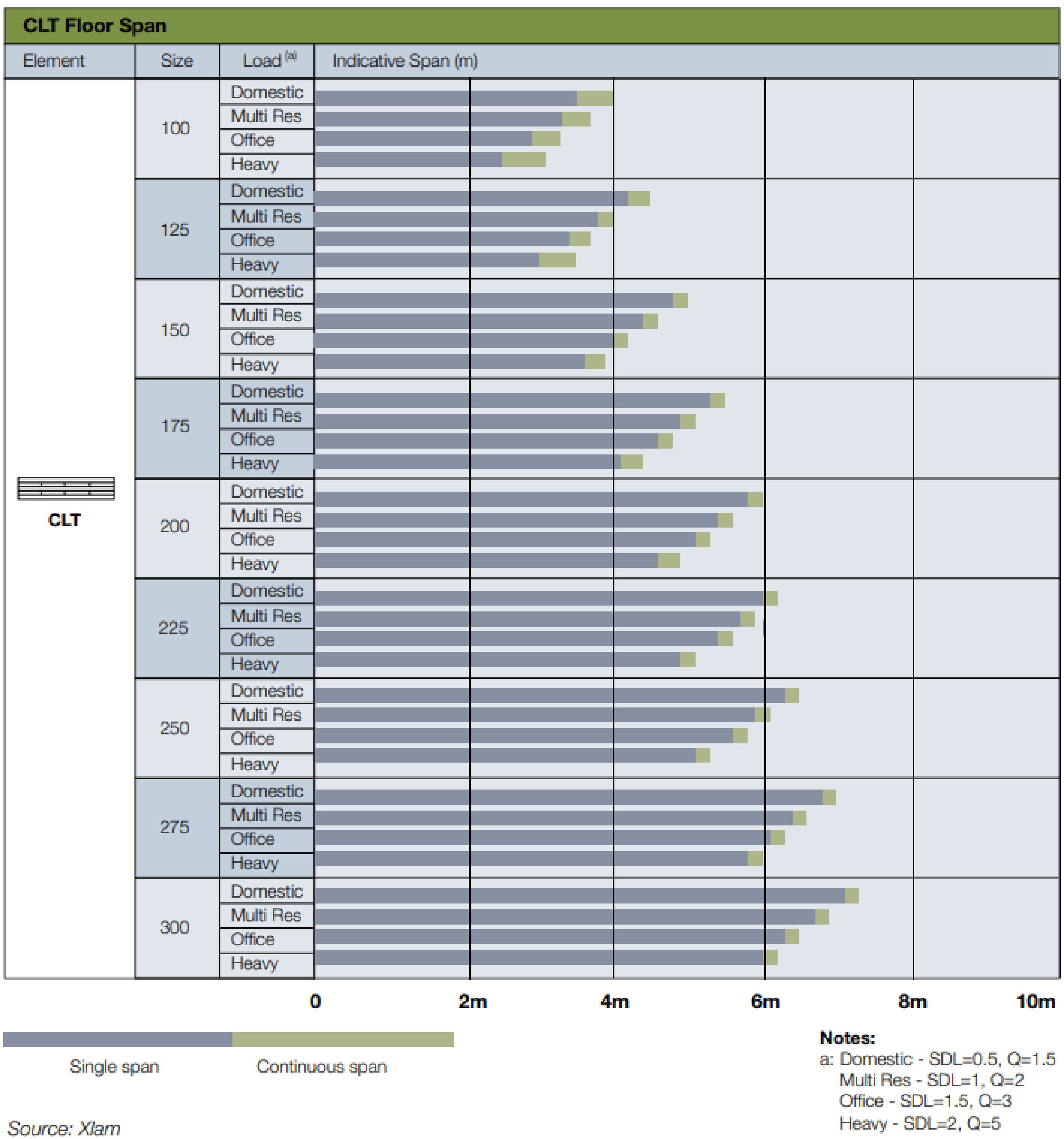
3x3haus

Design Calculations

Preliminary Design

Preliminary sizing of floor cassettes can be obtained from

• Approximate span to depth ratio estimates for a 5layer panel: span: depth = 25-27, therefore 5,620/25 = 225 mm



Wall Panel Selection: The walls running in the North/South direction will be taking the gravity loads of the entire building and will be exposed to lateral loads. The walls spanning in the East/West direction will primarily be taking lateral loads only. A preliminary wall size was chosen with consideration of the xlam design guide figure shown below. It was observed that for a height of 3.5m the deign capacity supports 272KN/m however this estimate is not subjected to the high level of wind loads that a 4-story building is anticipated to be subject to. An estimated reduction of its capacity by 20% still yielded enough strength to support the estimated loading of 200KN/m.

Panel Designation	Wall Height			
3 Layer Panels	2.8m	3.0m	3.5m	4.0m
CL3/85	129	115	85	71
CL3/105	250	226	171	144
CL3/115	302	274	209	178
CL3/125	386	352	272	231
CL3/135	446	412	321	275
The combined loading check allows for moment induced by eccentricity in addition simultaneous wind load of 0.5kpa.				

Figure 2: Xlam Axial wall capacity in KN/m.

Vertical Loading

The vertical design actions were determined in compliance with AS 1170.0,1 and following the manufactures specifications.

Permanent Loading (G):

G - Walls Loads

CLT self-weight (500 kg/m^3) = 2.08KN/m

SDL (1kpa) = 0.12KN/m

Total Wall Loads = 2.2KN/m

G - Floor Loads

CL5/225 = 1.3kpa – Xlam

SDL = 1kpa

Total Floor Loads = 2.3kpa

Q - Imposed Load

Q = 1.5kpa from AS/NZS 1170.1 Table 3.1, A

Structural Actions

4 Story Building Max Permanent Loads on Walls

	Loads	Wall 1	Wall 2	Wall 3
Level 3	Max UDL (KN/m)	11.63	11.63	2.20
	Max P (KN)	24.00	24.00	0.00
Level 2	Max UDL (KN/m)	25.15	32.46	14.96
	Max P (KN)	24.00	47.15	26.20
Level 1	Max UDL (KN/m)	38.67	59.50	28.14
	Max P (KN)	24.00	73.45	26.20
Ground	Max UDL (KN/m)	52.10	86.54	41.66
	Max P (KN)	50.40	99.70	28.14
SteelWork	Max UDL (KN/m)	58.30	99.70	48.60
	Max P (KN)	50.40	99.70	40.29

Table 1: Permanent Wall Loading at each Floor of 4 Story Building

4 Story Building Max Imposed Loads on Walls				
	Loads	Wall 1	Wall 2	Wall 3
Level 3	Max UDL (KN/m)	0.68	0.68	0.00
	Max P (KN)	1.49	0.00	0.00
Level 2	Max UDL (KN/m)	6.10	12.83	1.35
	Max P (KN)	1.50	14.47	1.49
Level 1	Max UDL (KN/m)	11.50	23.63	6.75
	Max P (KN)	1.50	25.76	1.49
Ground	Max UDL (KN/m)	16.90	34.43	12.15
	Max P (KN)	21.87	37.10	1.49
SteelWork	Max UDL (KN/m)	22.30	45.23	17.55
	Max P (KN)	21.87	37.10	1.49

Table 2: Imposed Wall Loading at each Floor of 4 Story Building

Load Combinations

STRENGTH	
LC1	1.35G
LC2	1.2G+1.5Q
LC3	1.2G + 1.5ψlQ
LC4	1.2G + Wu + ψcQ

Table 3: Strength Limit State Load cases

SERVICEABILITY	
LC1	G
LC2	ψsQ
LC3	ψlQ
LC4	Ws (uplift)

Table 4: Serviceability Limit State Load cases

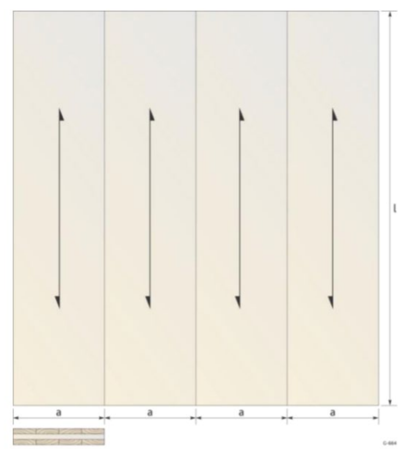
Floor Design

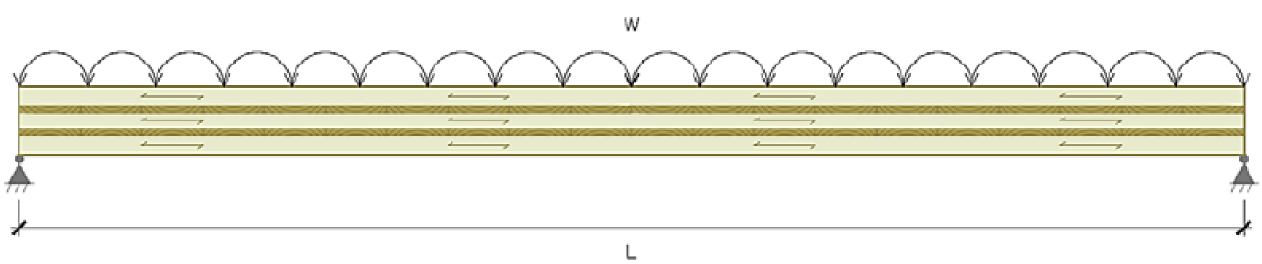
Deflection Performance

The Gamma Method is used to calculate the stiffness and hence deflection of the floor panel. The panel subject to the highest loading is the ceiling panels of the modules as it supports the floor panel of the above adjoining module.

Geometry and Loading

The floor assembly is made of multiple CLT panels placed next to each other in the same direction, thus acting as single directional slabs (one-way). The largest panels will be 5.4m long and 2m wide creating a span ratio of 2.7 and therefore is a one-way floor system.





CL5/225 CLT Panel

L = 5400mm

B_{eff} = 2000mm

$G_{ceiling} + G_{floor}$ = 4.6kPa

Q_{floor} = 1.5kPa - AS1170.1 Table 3.1, A

Serviceability Limit State: W_s = G = <u>4.6kPa</u>

Ultimate Limit State: $W_u = 1.2G + 1.5Q =$ <u>7.77kPa</u>

ti (mm)	h (a) mm	Lref² (mm2)	b/d	Ei (MPa)	Gr (MPa)	Ai (mm2)	γi	Ii (mm4)	A*h2 (mm4)	Eili eff (Nmm2)
45	90	2.92E+07	44.44	8000	40	90000	0.88	1.52E+07	7.29E+08	5.25E+12
45	45	0.00E+00	0	200	-	0				0.00E+00
45	0	2.92E+07	44.44	6000	40	90000	0.91	1.52E+07	0.00E+00	9.11E+10
45	45	0.00E+00	0	200	-	0				0.00E+00
45	90	2.92E+07	44.44	8000	40	90000	0.88	1.52E+07	7.29E+08	5.25E+12

Table 5: Finding the Effective Stiffness CL5/225

$$\gamma = \left[1 + \frac{\pi^2 E_i A_i}{G_R \frac{b}{d} l_{ref}^2}\right]^{-1}$$

$$EI_{eff} = \sum_{i=1}^{n}\left(E_i I_i + \gamma_i E_i A_i a_i^2\right)$$

EI_{eff} (Nmm2) = 1.06E+13

Maximum deflection

Δmax (mm) = 9.62mm

Check L/ Δ = 561 > 300 therefore Ok

CL5/225 Panel satisfies the deflection performance criteria.

Dynamic Performance

The dynamic performance of a CLT floor is governed by stiffness, mass and damping (additional layers of furniture etc). The stiffer, heavier and more layers a floor has the higher the performance.

This section follows wood solutions Design Guide 50 section 3.6.5.2 to design for vibration.

1.Check the deflection of the floor under a 1KN point load:

$$\Delta 1KN = \frac{PL\hat{}2}{48EIeff}$$

Δ_{1KN} = 0.31mm <1.5mm ∴ok

2.Check dynamic frequency:

$$F1 = \frac{\pi}{2l^2}(\frac{EIeff}{m})^{1/2}$$

L = 5400mm

M = 225 kg/m2

F1 = 16Hz > 8Hz ∴ok

3.Check FPI acceptance criteria:

$$\frac{F1}{\Delta 1\mathrm{KN}^{0.7}} > 13$$

37 > 13 ∴ok

CL5/225 Panel satisfies the dynamic performance criteria.

Strength Performance – Bending Capacity

The Section Bending Capacity for strength limit state must satisfy ϕM > M*

Where:

M* is the design action effect in bending
ϕM = ϕb*k1*k4*k6*k9*k12*f'b*Zeff

	STRENGTH	
LC1	1.35G	6.21
LC2	1.2G+1.5Q	7.77
LC3	1.2G + 1.5ψlQ	6.42
LC4	1.2G + Wu + ψcQ	6.78

Table 6: W* for load combinations

Moment Capacity		Notes/Comments
ϕb	0.85	Reduction Factor
k4	1	Seasoned Timber
k6	1	Temperature Factor
K9	1	Strength Sharing Factor
k12	1	Stability Factor
f'b (MPa)	14	Bending Strength - Xlam
Eieff (Nmm^2)	1.06E+13	Effective Stiffness
E1 (Mpa)	8000	Outer CLT Layers
Zeff (mm^3)	1.18E+07	Section Modulus

Table 7: Factors for Moment Capacity

	LC1	LC2	LC3	LC4
k1 (Load Duration Factor)	0.57	0.8	0.57	1
ϕM (KNm)	79.84	112.05	79.84	140.07
M* (KNm)	22.64	28.32	23.40	24.71
CL5/225 Safe	28.35%	25.28%	29.31%	17.64%

Table 8: Analysis of Moment Capacity per Load Combination

ϕM > M* ∴ CL5/225 satisfies the Bending Strength criteria.

Strength Performance – Shear Capacity

The Section Shear Capacity for strength limit state must satisfy ϕV > V*

$$\therefore \varphi V = \frac{\varphi_s k_1 k_4 k_6 t_v EI_{eff} b_{eff}}{(EQ)}$$

$$(EQ)_L = E_1 t_1 b_{eff} a_1 + E_2 t_2 b_{eff} a_2 + E_3 \frac{t_3}{2} b_{eff} a_3$$

$$(EQ)_R = E_1 t_1 b_{eff} \left(a_1 - \frac{t_3}{2}\right) + E_2 t_2 b_{eff} \left(a_2 - \frac{t_3}{2}\right)$$

Shear Capacity		Notes/Comments
ϕs	0.85	Reduction Factor
k4	1	Seasoned Timber
k6	1	Temperature Factor
tv	3.8	
EIeff Nmm2	1.06E+13	Effective Stiffness
beff (m)	2	CLT panel width
E1 (MPa)	8000	Outer Longitudinal
E2 (MPa)	200	Transverse layers
E3 (MPa)	6000	Inner Longitudinal
EQ L Nmm	6.78E+10	statical moment of area
EQ R Nmm	4.90E+10	statical moment of area
f'b mpa	14	Bending Stress - Xlam

Table 9: Factors for Shear Capacity

	LC1	LC2	LC3	LC4

k1 (Load Duration Factor)	0.57	0.8	0.57	1
ϕVL (KN)	574.99	807.01	574.99	1008.76
ϕVR (KN)	795.97	1117.15	795.97	1396.44
V* (KN)	16.77	20.98	17.33	18.31
	2.92%	2.60%	3.01%	1.81%
	2.11%	1.88%	2.18%	1.31%

Table 10: Analysis of Shear Capacity per Load Combination

ϕV > N* ∴ CL5/225 satisfies the Shear Strength criteria.

Wall Design

Geometry and Loading

From Preliminary selection a CL3/125 CLT panel will be analysed in conjunction with the applied design actions.

CLT panel: CL3/125

tp = 125mm

ti = 45mm

L = 3400mm

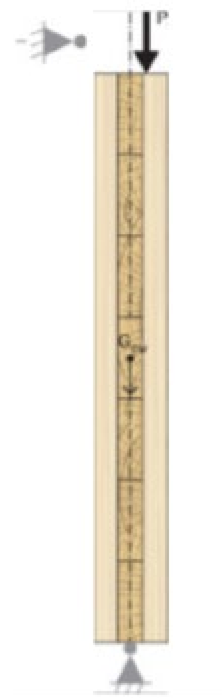
Beff = 1000mm

Et = tp/15 = 8.33mm – Location of eccentrically placed load.

P_G = 52.10 KN/m and 50.40 KN from table 1.

P_Q = 16.90 KN/m and 21.87 KN from table 2.

Wall 1 is critical as Wall 2 has twice the stiffness (Two module walls connected)



Effective Stiffness for Panel

The EI effective, with gamma value of 1 can be used for strength checks. Therefore gamma is not calculated for this wall design.

ti (mm)	h (a) mm	Ei (MPa)	Ai (mm2)	Ii (mm4)	A*h2 (mm4)	Eili eff (Nmm2)
45	45	8000	90000	7.20E+07	1.6E+06	5.89E+11
35	0	200	0	0	0	0.00E+00
45	45	6000	90000	7.20E+07	1.6E+06	5.89E+11

Table 11: Finding the Effective Stiffness CL3/125

$$EI_{eff} = \sum_{i=1}^{n} \left(E_i I_i + \gamma_i E_i A_i a_i^2 \right)$$

Strength Performance – Axial Compressive Capacity

The Axial Capacity for Compressive design loads must satisfy φNc > N*.

φNc = φc*k1*k4*k6*k12*f'c*Ac

Axial Capacity		Notes/Comments
φc	0.85	Reduction Factor
k4	1	Seasoned Timber
k6	1	Temperature Factor
k12	0.31	Stability Factor
f'c (MPa)	18	Compressive Strength - Xlam
Ac (mm2)	90000	Effective area
r	0.25	
g13	1	Effective length Factor
g28	1	Effective length Factor
S	24.25	Slenderness Coefficient
ρc	1.05	Material Constant
ρc.S	25.44	

Table 12: Factors for Axial Compressive Strength

$$k_{12} = \frac{200}{(\rho_c - S)^2}$$

$$\rho_c = 11.39 \left(\frac{E}{f_c'} \right)^{-0.408} r^{-0.074}$$

$$S_s = 0.3 g_{13} g_{28} L \left(\frac{EA_{eff}}{EI_{eff}} \right)^{0.5}$$

Axial Capacity	LC1	LC2	LC3	LC4
k1 (Load Duration Factor)	0.57	0.8	0.57	1
φNc Capacity (KN/m)	242.53	340.40	242.53	425.50
N* (KN/m)	70.34	87.87	72.66	70.252
	29.00%	25.81%	29.96%	16.51%

Table 13: Analysis of Axial Compressive Capacity per Load Combination

φNc > N* ∴ok

Strength Performance – Axial Bending Capacity due to Eccentricity

Calculate the panels Bending Capacity for potential eccentric loading conditions. The Bending Capacity for eccentric design loads must satisfy φM > M*.

$\varphi M = \varphi b*k1*k4*k6*k9*k12*f'b*Zeff$

Bending Capacity (Eccentricity)		Notes/Comments
φb	0.85	Reduction Factor
k4	1	Seasoned Timber
k6	1	Temperature Factor
k9	1	Strength Sharing Factor
k12	1	Stability Factor
f'b (MPa)	14	Bending Strength - Xlam
Zeff (mm3)	2.55E+06	Section Modulus

Table 14: Factors for Axial Bending Strength

$$Zeff = \frac{EIeff}{E1} x \frac{2}{tp}$$

K12 = 1.0 - slenderness coefficient for floor, assumed no torsion

M* = N x et

Bending Capacity (Eccentricity)	LC1	LC2	LC3	LC4
k1 (Load Duration Factor)	0.57	0.8	0.57	1
φMb Capacity (KNm)	17.28	24.25	17.28	30.31
M* (KNm)	0.59	0.73	0.61	0.59
	3.39%	3.02%	3.50%	1.93%

Table 15: Analysis of Axial Bending Capacity per Load Combination

φMb > M* ∴ok

Strength Performance – Combined Actions Check

Combined bending and compression members shall be proportioned to satisfy the follow equations.

$$\text{Check 1} = \left(\frac{M*}{\phi\text{Mb}}\right)^2 + \frac{N*}{\phi Nc} \leq 1$$

and

$$\text{Check 2} = \left(\frac{M*}{\phi\text{Mb}}\right) + \frac{N*}{\phi Nc} \leq 1$$

Combined Actions				
	LC1	LC2	LC3	LC4
M*	0.59	0.73	0.61	0.59
φMb	17.28	24.25	17.28	30.31
N*	70.34	87.87	72.66	70.25
φNc	242.53	340.40	242.53	425.50
Check 1 <1	29.12%	25.91%	30.08%	16.55%
Check 2 <1	32.39%	28.83%	33.46%	18.44%

Table 16: Analysis of Combined Actions per Load Combination

Strength Performance – Bearing Check

Calculate loaded cross-sectional area of elements, perpendicular to grain in story. Perpendicular to grain crushing is a strength test, but as the wood crushes, it still transmits loads of bearings and seldom causes any collapse. As the crushing continues, the structure deforms, so bearing perpendicular to grain is pragmatically a matter of serviceability rather than a matter of energy. This must also be measured as a strength test to ensure conformity with AS 1720.1.

φNb = φb*k1*k4*k6*k7*f'p*Api

Bearing Capacity		Notes/Comments
Geometry		
tp Wall (mm)	125	Wall thickness
tp Floor (mm)	225	Floor thickness
k7	1	length of bearing Factor
beff (mm)	1000	Wall effective width
Api (mm2)	2.38E+05	Loaded cross-sectional area of elements perpendicular to grain in storey
Bearing Capacity		
φ	0.8	Reduction Factor
k4	1	Seasoned Timber
k6	1	Temperature Factor
f'c90 (MPa)	8.9	Compression Strength (Perp to grain)

Table 17: Factors for Bearing Strength

$$A_{pi} = Max\,(b_4 + \frac{d_3}{4}, k_7 b_4) x b_3$$

Bearing Capacity	LC1	LC2	LC3	LC4
k1	0.57	0.8	0.57	1
φNb (KN)	963.87	1352.80	963.87	1691.00
N* (KN)	68.85	94.2	74.4	72.55
	7.14%	6.96%	7.72%	4.29%

Table 18: Analysis of Combined Actions per Load Combination

φNb > N* ∴ok

Vertical Wall Settlements

Axial shortening of a building is a long-term problem. Therefore, all loads considered in the estimation of shortening are long-term gravity loads. It is a serviceability issue and uses a load combination $G + \psi\, lQ$.

$\delta t = \delta_{s,l} + \delta_{s,p} + \delta_{c,l} + \delta_{c,p} + \delta_j$

$\delta_{s,l} = up * \Delta mc * L$

$\delta_{s,p} = up * \Delta mc * d_p$

$$\delta c, l = \sum_{floors} \frac{j_2\ N_{c,i} L_i}{E_i A_{p,i}}$$

$$\delta c, p = \sum_{floors} \frac{j_2\ N_{c,i}\ d_{2,i}}{E_i A_{p,i}}$$

$\delta_j = n_{joints} * \delta_{gaps}$

	Differential Settlement			
	Wall 1 δtotal (mm)	Wall 2 δtotal (mm)	Wall 3 δtotal (mm)	ΔδMax
Third Level	5.64	4.99	5.01	0.65
Second Level	8.33	9.00	7.36	1.63
First Level	9.61	11.53	8.61	2.92
Ground Level	10.88	14.07	9.89	4.18

Table 19: Total Settlement of each wall and highest differential settlement

Shortening Wall 1	Ground Level	First Level	Second Level	Third Level	Notes/Comments
Shrinkage					
Parallel to grain					
u	2.70E-03				
up (mm/mm/%change in MC)	0.0000675				Tangential Movement
Δmc %	3.00				Change in moisture content
δ(s,l) (mm)	0.689	0.69	0.69	0.69	Total shrinkage parallel to grain
Perpendicular to grain					
up	0.0027				
up (mm/mm/%change in MC)	0.0027				Tangential Movement
Δmc %	4.00				Change in moisture content
δ(s,p) (mm)	4.86	4.86	4.86	3.78	Total shrinkage perpendicular to grain
Deformation and Creep					
Parallel to grain					
j2	2				
N* (KN)	52.10	38.67	25.15	11.63	Applied Long term action
L (mm)	3400				Length of wall
Ei (MPa)	8000				Modulus of elasticity
Ap (mm2)	9.00E+04				Loaded cross sectional area of perpendicular elements
δ(c,l) (mm)	1.97	1.46	0.95	0.44	Total compression parallel to grain
Perpendicular to grain					
j2	2				
N* (KN)	52.10	38.67	25.15	11.63	Applied Long term action
dp (Floor)	270				
Ei (MPa) Floor	266.67				Modulus of elasticity perpendicula to grain
dp (Wall)	90				Effective thickness
Ei (MPa) Wall	200				Modulus of elasticity perpendicula to grain
Ap (mm2)	2.38E+05				
δ(c,p) (mm)	2.96	2.20	1.43	0.33	Total compression perpendicular to grain
Settlement of joints					
n(joints)	2				
δgap (mm)	0.2				Prefabricated in factory
δj (mm)	0.4	0.4	0.4	0.4	Total closure of joints
δtotal (mm)	10.88	9.61	8.33	5.64	Total estimated shortening of the building

Table 20: Example of Settlement Calculation (Wall 1)

Beam Design

Glulam 18 130x330 beam is selected and will be checked for shear and bending capacity.

ϕM=ϕb*k1*k4*k6*k9*k12*f'b*Zeff

ϕb	k1	k4	k6	S1	pb	k9	k12
0.85	0.8	1	1	0	1	1	1

Table 21: Factors for Bending Strength

f'b mpa	Ieff (mm4)	Zeff mm3	ϕM (KNm)	M* (KNm)
45	3.89E+08	5.99E+06	183.28	70

Table 22: Analysis or Bending Capacity

ϕM>M* ∴ok

Wind Design AS1170.2

Site Wind Speed

Using section2.2 the wind speed at the site is:

$$V_{des,\theta} = V_{sit,B} = V_R M_d \left(M_{z,cat} M_s M_t\right)$$

Each coefficient is found using Section 3 of the standards.

Terrain category 3 was chosen due to the site being located in city and it was assumed similar sized buildings were surrounding it yet minimal shielding for the 4 story building as no information was provided beyond the immediate surrounding. It was also assumed no hill was present.

Directions	**V(25)**	**V(500)**	**M(d)**	**TC**	**M(z,cat)**
SW	37	45	0.9	3	0.86
W	37	45	1	3	0.86
NW	37	45	0.95	3	0.86
N	37	45	1	3	0.86
NE	37	45	0.85	3	0.86
E	37	45	0.8	3	0.86
SE	37	45	0.8	3	0.86
S	37	45	0.85	3	0.86
Direction	**Shielding?**		**M(s)**	**M(h)**	**V(sit,β) m/s**
SW	No		1	1	34.830
W	no		1	1	38.700
NW	no		1	1	36.765
N	no		1	1	38.700
NE	no		1	1	32.895
E	no		1	1	30.960
SE	No		1	1	30.960
S	Yes		0.9625	1	31.661

Table 21: Coefficients for determining site wind speed.

V_R = 45

M_d = 1

$M_{z,cat}$ = 0.86

M_s = 1

M_t = 1

V_{sitB} = 38.7 m/s

Site Wind Pressure

<2.4.1> Provides the formula for finding the wind pressure on the structure.

$$p = 0.5 p_{air} V_{des}^{2} C_{fig} C_{dyn}$$

P_{air} = 1.2kg/m^3

C_{dyn} = 1 as non of the elements will have a natural frequency of less then 1 Hz

$V_{des\theta}$ = 38.7 m/s

p = 898.614 C_{fig}

Using the buildings dimensions and openings the pressure can be found below with various cases considered. The aerodynamic shape factor is found below using section 5 of the standards.

The coefficients for internal and external pressure were calculated and can be seen in appendix 1.

Pressure

Following finding all the aerodynamic shape factors the pressure acting on each surface can be found and the worst case scenario determined using:

$$p = 0.5 p_{air} V_{des}^2 C_{fig} C_{dyn}$$

4 Story Northern Wind

Northern Wind	Acting location	p 1 (pa)	p 2 (pa)
Windward Wall		575.11	0
Leeward Wall		-192.66	0
Side Wall	0-h	-467.28	0
	h-2h	-359.45	0
	2h-3h	-215.67	0
	3h+	0	0
Roof	0-0.5h	-647.00	-287.56
	0.5h-h	-647.00	-287.56
	h-2h	-359.45	0
	2h-3h	-215.67	71.89
	3h+	0	0

Table 22: External pressure

Northern Wind		Acting location	p 1 (pa)	p 2 (pa)
Case 1	None	Surface	-143.78	0.00
Case 2	**N/E**	Surface	-206.32	-81.23
	N/W	Surface	-199.85	-141.62
	N/S	Surface	-214.95	-7.91
Case 3	N/0	Surface	575.11	0.00
Case 4	E/0	0-h	-467.28	0.00
		h-2h	**-359.45**	0.00
		2h-3h	-215.67	0.00
Case 5	W/0	0-h	-467.28	0.00
		h-2h	**-359.45**	0.00
		2h-3h	-215.67	0.00
Case 6	S/0	Surface	-194.10	0.00

Table 23: Internal Pressure

Windward:	575.11 pa
Leeward:	-192.66 pa
Internal :	-143.784 pa
	624.00 pa
Net Pressure	**0.62 kpa**
Roof uplift	
Largest External uplift	-647.00 pa
Internal pressure @ ext roof uplift	575.11 pa
	1.22 kpa

Table 24: Worst cases

For the Roof pressure acting down along the structure:

Location	Roof Down pressure (pa)	
0-0.5h	179.72	0.18
0.5h-h	179.72	0.18
h-2h	359.45	0.36
2h-3h	287.56	0.29

Table 25: Roof downward pressure

Floor	A_x m^2	A_y m^2	F_x (kN)	F_y (kN)	F_x CUM	F_y CUM
R	5.79	13.42	3.61	8.37	3.61	8.37
3	41.96	97.1	26.18	60.59	29.80	68.96
2	41.96	97.1	26.18	60.59	55.98	129.55
1	41.96	97.1	26.18	60.59	82.16	190.14
G	41.96	97.1	26.18	60.59	108.34	250.73

Table 26: Overall forces distributed per wall for Northern wind.

4 Story Western Wind

Western Wind	Acting location	p 1 (pa)	p 2 (pa)
Windward Wall	Surface	575.11	0
Leeward Wall	Surface	-359.45	0
Side Wall	0-h	-467.28	0
	h-2h	0	0
	2h-3h	0	0
	3h+	0	0
Roof	0-0.5h	-647.00	-287.56
	0.5h-h	-647.00	-287.56
	h-2h	0	0
	2h-3h	0	0
	3h+	0	0

Table 27: External pressure

Western Wind		Acting location	p 1 (pa)	p 2 (pa)
Case 1	None	Surface	-143.78	0
Case 2	**N/E**	0-h	-321.34	-196.26
	N/W	0-h	-396.83	-336.44
	N/S	0-h	-225.73	-18.69
Case 3	N/0	0-h	-467.28	0
		h-2h	-359.45	0
		2h-3h	-215.67	0
Case 4	E/0	surface	-359.45	0
Case 5	W/0	surface	575.11	0
Case 6	S/0	0-h	**-467.28**	**0**
		h-2h	-359.45	0
		2h-3h	-215.67	0

Table 28: Internal Pressure

Windward:	575.11 pa
Leeward:	-359.45 pa
Internal :	-143.78 pa
	790.78 pa
Net Pressure	**0.79 kpa**
Roof uplift	
Largest External uplift	-647.00 pa
Internal pressure @ ext roof uplift	575.11 pa
	1.22211504 kpa

Table 29: Worst cases

Location	Roof Down Pressure (pa)	Roof Down Pressure (kpa)
0-0.5h	179.72	0.18
0.5h-h	71.89	0.07
h-2h	215.67	0.22
2h-3h	359.45	0.36

Table 30: Roof downward pressure

Floor	A_x m^2	A_y m^2	F_x (kN)	F_y (kN)	F_x CUM	F_y CUM
R	5.79	13.42	5.79	13.42	4.58	10.61
3	41.96	97.1	41.96	97.10	33.18	76.78
2	41.96	97.1	41.96	97.10	33.18	76.78
1	41.96	97.1	41.96	97.10	33.18	76.78
G	41.96	97.1	41.96	97.10	33.18	76.78

Table 31: Overall forces distributed per wall for Western wind.

2 Story Northern Wind

Northern Wind	Acting location	p 1 (pa)	p 2 (pa)
Windward Wall		575.11	0.00
Leeward Wall		-199.13	0.00
Side Wall	0-h	-467.28	0.00
	h-2h	-359.45	0.00
	2h-3h	-215.67	0.00
	3h+	-143.78	0.00
Roof	0-0.5h	-647.00	-287.56
	0.5h-h	-647.00	-287.56
	h-2h	-359.45	0.00
	2h-3h	-215.67	71.89
	3h+	-143.78	143.78

Table 32: External Pressure

Northern Wind		Acting location	p 1 (pa)	p 2 (pa)
Case 1	None	Surface	-143.78	0.00
Case 2	**N/E**	Surface	-209.20	-77.64
	N/W	Surface	-213.51	-25.88
	N/S	Surface	-210.64	-63.98
Case 3	N/0	Surface	**575.11**	0.00
Case 4	E/0	0-h	-467.28	0.00
		h-2h	**-359.45**	0.00
		2h-3h	-215.67	0.00
Case 5	W/0	0-h	-467.28	0.00
		h-2h	**-359.45**	0.00
		2h-3h	-215.67	0.00
Case 6	S/0	Surface	-194.10	0.00

Table 33: Internal Pressure

Windward:	575.11
Leeward:	-199.13
Internal :	-143.78
	630.47
Net Pressure	**0.63**
Roof uplift	
Largest External uplift	-647.00
Internal pressure @ ext roof uplift	575.11
	1.22

Table 34: Worst cases

Location	Roof Down pressure (pa)	
0-0.5h	179.72	0.18
0.5h-h	179.72	0.18
h-2h	359.45	0.36
2h-3h	287.56	0.29

Table 35: Roof downward pressure

Floor	A_x m^2	A_y m^2	F_x (kN)	F_y (kN)	F_x CUM	F_y CUM
R	5.37	12.50	3.39	7.88	3.39	7.88
1.00	38.86	90.41	24.50	57.00	27.89	64.88
G	38.86	90.41	24.50	57.00	52.39	121.88

Table 36: Overall forces distributed per wall for Northern wind.

2 Story Western Wind

Western Wind	Location	p 1 (pa)	p 2 (pa)
Windward Wall	Surface	575.11	0.00
Leeward Wall	Surface	-359.45	0.00
Side Wall	0-h	-467.28	0.00
	h-2h	-359.45	0.00
	2h-3h	0.00	0.00
	3h+	0.00	0.00
Roof	0-0.5h	-647.00	-287.56
	0.5h-h	-647.00	-287.56
	h-2h	-359.45	0.00
	2h-3h	0.00	0.00
	3h+	0.00	0.00

Table 37: External Pressure

Western Wind		Location	p 1 (pa)	p 2 (pa)
Case 1	None	Surface	-143.78	0.00
Case 2	**S/E**	0-h	-314.16	-182.60
		h-2h	**-297.62**	-204.88
	S/W	0-h	-248.02	-60.39
		h-2h	**-234.36**	-46.73
	S/N	0-h	-294.03	-144.50
		h-2h	**-261.68**	-115.02
Case 3	N/0	0-h	-467.28	0.00
		h-2h	**-359.45**	0.00
		2h-3h	-215.67	0.00
Case 4	E/0		-359.45	0.00
Case 5	W/0		575.11	0.00
Case 6	S/0	0-h	**-467.28**	0.00
		h-2h	-359.45	0.00
		2h-3h	-215.67	0.00

Table 38: Internal Pressure

Windward:	575.11 pa
Leeward:	-359.45 pa
Internal :	-143.78 pa
	790.78 pa
Net Pressure	**0.79 kpa**
Roof uplift	
Largest External uplift	-647.00 pa
Internal pressure @ ext roof uplift	575.11 pa
	1.22 kpa

Table 39: Worst cases

Location	Roof Down Pressure (pa)	Roof Down Pressure (kpa)
0-0.5h	179.72	0.18
0.5h-h	179.72	0.18
h-2h	359.45	0.36
2h-3h	215.67	0.22

Table 40: Roof downward pressure

Floor	A_x m^2	A_y m^2	F_x (kN)	F_y (kN)	F_x CUM	F_y CUM
R	5.37	12.50	4.25	9.88	4.25	9.88
1.00	38.86	90.41	30.73	71.49	34.98	81.37
G	38.86	90.41	30.73	71.49	65.71	152.86

Table 41: Overall forces distributed per wall for Western wind.

Now that all the pressures have been found forces can be used in the lateral design section.

Earthquake AS1170.4

<T3.2>
The Hazard design factor takes into account the location of the site.
Melbourne Z=0.9

<T4.1>
Due to no Geotechnical data being provided on the soil at the location, and assumption was made that the soil will be soft soil being an inner city location.
Assume soft soil site = De

<T3.1>
Annual probability factor of exceedance is based on how likely the event is to occur, usually 1/500 is chosen as Earthquakes are rare occurrences.
K_p = 1 for 1/500

<T2.1>
Importance level 2 building with less then 50m height is used to obtain the category for the earthquake design, being a category 2.
The overall weights per module are then computed.

Module	**Weight (kN)**
2 Person module	622.43
1 Person module	467.53
Roof 1 person module	129.09
Roof 2 person module	177.7
Roof 4 story shaft	79.36
Roof 2 story shaft	56.96
Shaft 4 story	300
Shaft 2 story	220

Table 42: Weights per module

4 Story

The following involves finding the Vertical distribution of loading for the 4 story building following section 6 of the standards.

H_n=14.54m

Natural period of structure:

$$T_1 = 1.25k_t h_n^{0.75}$$

K_t =0.05 – other structures (timber)

<u>T_1 = 0.47 s</u>

Total Weight for the 4 story building:

W_t = 6207.176 kN

<T6.4>

Spectral shape factor is determined from the equations of spectra:

check 1.98/T ≤ 3.68   1.98/0.47 = 4.25, Not Ok

Use 3.68

<T6.5A>

Table provide coefficients for finding the distribution of forces.

Timber shear walls	
μ	3
S_p	0.67
S_p/μ	0.22
μ/S_p	4.5

Table 43: Timber shear wall coefficients

<6.2.1>

Base shear force

$$V = \left[k_p Z C_h T_1 \frac{S_p}{\mu}\right] W_t$$

V= 452.28 Kn

$$F_i = \frac{W_i h_i^k}{\sum_{j=1}^{n}\left(W_j h_j^k\right)} V$$

$\sum_{j=1}^{n}\left(W_j h_j^k\right)$= 48311.96 kN

$W_i h_i^k$ = seismic weight of structure at ith level times the height of level I above base of the structure

Vertical distribution of forces	Force (kN)	Cumulative Force (kN)
F1	42.43	407.47
F2	82.06	365.04
F3	121.68	282.98
R	161.30	161.30

Distribution of Moments	Moment (kNm)
M1	144.27
M2	702.24
M3	1943.37
R	4137.08

Table 44: Distributed forces and moments

2 Story

Similarly the following involves finding the vertical distribution of loading for the 4 story building following section 6 of the standards.

H_n= 7.74m
Natural period of structure:

$$T_1 = 1.25 k_t h_n^{0.75}$$

K_t =0.05 – other structures (timber)
T_1 = 0.29 s

Total Weight for the 2 story building:
W_t = 2983.67 kN

<T6.4>
Spectral shape factor is determined from the equations of spectra:
Check 1.98/T ≤ 3.68 1.98/0.47 = 6.83, Not Ok
Use 3.68

<T6.5A>
Table provide coefficients for finding the distribution of forces.

Timber shear walls	
μ	3
S_p	0.67
S_p/μ	0.22
μ/S_p	4.5

Table 45: Timber shear wall coefficients

<6.2.1>
Base shear force

$$V = \left[k_p Z C_h T_1 \frac{S_p}{\mu}\right] W_t$$

V= 217.40 Kn

$$F_i = \frac{W_i h_i^k}{\sum_{j=1}^{n}\left(W_j h_j^k\right)} V$$

$\sum_{j=1}^{n}\left(W_j h_j^k\right)$= 48311.96 kN

$W_i h_i^k$ = seismic weight of structure at ith level times the heigh of level I above base of the structure

Vertical distribution of forces	Force (kN)	Cumulative Force (kN)
F1	77.48	227.43
R	149.95	149.95

Distribution of Moments	Moment (kNm)
M1	263.44
M2	1283.09

Table 46: Distributed forces and moments

The forces located act at the point where the floor is located as that is the interface between modules where the most mass is present.

Lateral Loading

In Plane Stiffness – Panel contribution

Following Wood solutions design guide 50, for the lateral load distribution per wall, the relative stiffness for each shear wall should be calculated. The stiffness is the force over unit deformation.

Calculate the in plane bending deformation of the shear wall, sue to a 1 kN load:

$$I = \frac{d_o b^3}{12}$$

$$\delta_m = \frac{F_k h^3}{3EI}$$

To calculate the shear deformation of the wall:

$$\delta_v = \frac{F_k h}{GA_z}$$

$G_v = 0.75$ G

$A_z = d_{gross}{}^{b}$

The E, G values were obtained from the XLAM supplier handbook.

d0 (mm)	90
b (mm)	2500
I (mm^4)	1.17188E+11
Fk (N)	1000
h (mm)	2875
Eav (MPa)	7333
δm (mm)	0.009217843
G (MPa)	533
Gv (MPa)	399.75
Az (mm^2)	225000
δv (mm)	0.031964422

Table 47: Information for wall deformation

The following is repeated from the various lengths of walls to be considered.

d (mm)	**b (mm)**	**d0 (mm)**	**h (mm)**	**G (MPa)**	**E (MPa)**	**Fk (N)**	**E av (MPa)**	**Gv (MPa)**	**Az (mm^2)**
125	12000	90	3400	533	8000	1000	7333.33	399.75	1080000
125	10400	90	3400	533	8000	1000	7333.33	399.75	936000
125	6000	90	3400	533	8000	1000	7333.33	399.75	540000
125	5400	90	3400	533	8000	1000	7333.33	399.75	486000
125	4400	90	3400	533	8000	1000	7333.33	399.75	396000
125	4000	90	3400	533	8000	1000	7333.33	399.75	360000

Table 48: Panel data

The extension of the tie rods δz and displacement in one of the two joints between the wall and ceiling δf can be calculated as follows:

$$\delta_z = \frac{F_k h^2}{b^2 c_z n}$$

C_z is the vertical stiffness from the connection supplier handbook

N is the number of expansion rods per end of panel.

Convert the vertical stiffness c_z to horizontal stiffness using:

$$d_x = \frac{h d_y}{b} \qquad c_z = \frac{F_k}{d_x}$$

Calculated the displacement between wall and ceiling:

$$\delta_f = \frac{F_k}{n c_f}$$

C_f is the connection stiffness from a supplier handbook

N is the number of fixings per panel at 1m lengths.

Therefore the total displacement per unit force can be found by summing up the displacements

$$\delta_t = \delta_m + \delta_v + \delta_z + \delta_f$$

(mm^4)	**δm (mm)**	**δv (mm)**	**Cz**	**n**	**δz (mm)**	**Cf**	**n**	**δf (mm)**	**δt (mm/KN)**
1.296E+13	0.000138	0.007875	12381	2	0.0032	11240	8	0.0111	0.0224
8.43648E+12	0.000212	0.009087	12381	2	0.0043	11240	8	0.0111	0.0247
1.62E+12	0.001103	0.015751	12381	2	0.0130	11240	8	0.0111	0.0409
1.18098E+12	0.001513	0.017501	12381	2	0.0160	11240	5	0.0178	0.0528
6.3888E+11	0.002796	0.021478	12381	2	0.0241	11240	3	0.0297	0.0780
4.8E+11	0.003722	0.023626	12381	2	0.0292	11240	3	0.0297	0.0862

Table 49: Computing total displacement per unit force

The relative contributions for each panel can therefore be checked below:

	δt (mm)	**δm (mm)**	**δv (mm)**	**δz (mm)**	**δf (mm)**	**Total**
T1	0.02	0.62%	35.20%	14.49%	49.70%	100.00%
T2	0.02	0.86%	36.74%	17.45%	44.96%	100.00%
T3	0.04	2.69%	38.47%	31.67%	27.16%	100.00%
T4	0.05	2.86%	33.13%	30.31%	33.69%	100.00%
T5	0.08	3.58%	27.52%	30.90%	38.00%	100.00%
T6	0.09	4.32%	27.41%	33.86%	34.41%	100.00%

Table 50: Panel contributions for displacement

Stiffness per wall length is found to be:

K=Force/Displacement

Wall Length (mm)	K (N/mm)
12000	44690.51
10400	40427.11
6000	24424.63
5400	18933.38
4400	12813.24
4000	11603.40

Table 51: Stiffness for each individual wall element

ΣYi (m)	ΣKxi (N/mm)	ΣXi (m)	ΣKyi (N/mm)
3.49	1218407.87	5.18	817045.99

Table 52: Summation of stiffness of 4-story building in the x and y direction

Level 3 Kx (N/mm)	Level 3 Ky (N/mm)	Level 2 Kx (N/mm)	Level 2 Ky (N/mm)	Level 2 Kx (N/mm)	Level 2 Ky (N/mm)	Level 1 Kx (N/mm)	Level 1 Ky (N/mm)	Ground Kx (N/mm)	Ground Ky (N/mm)
178536.76	208102.02	346623.70	202981.33	346623.70	202981.33	346623.70	202981.33	346623.70	202981.33

Table 53: Total floor stiffness in the x and y direction

Considering Wind Loading, the following table has been split up over 2 pages. It consists of each wall stiffness with a relevant wall load.

3rd Story										W Load	
Wall No	**L (mm)**	**Direction**	**Yi(mm)**	**Xi(mm)**	**K (N/mm)**	**Kx (N/mm)**	**Ky (N/mm)**	**1kN x%**	**1kN y%**	**F (kN) Wx**	**F (kN) Wy**
3.1x	10400	x	5200	0	40427.11	40427.11	0	22.64%	0.00%	8.55	0.00
3.2x	6000	x	235	0	24424.63	24424.63	0	13.68%	0.00%	5.17	0.00
3.3x	4400	x	5200	0	12813.24	12813.24	0	7.18%	0.00%	2.71	0.00
3.4x	4000	x	6600	0	11603.40	11603.40	0	6.50%	0.00%	2.45	0.00
3.5x	4000	x	5400	0	11603.40	11603.40	0	6.50%	0.00%	2.45	0.00
3.6x	10400	x	5200	0	40427.11	40427.11	0	22.64%	0.00%	8.55	0.00
3.7x	6000	x	235	0	24424.63	24424.63	0	13.68%	0.00%	5.17	0.00
3.8x	4400	x	5200	0	12813.24	12813.24	0	7.18%	0.00%	2.71	0.00
3.1y	5400	y	0	6400	18933.38	0	18933.38	0.00%	9.10%	0.00	7.95
3.2y	10400	y	0	2250	40427.11	0	40427.11	0.00%	19.43%	0.00	16.98
3.3y	12000	y	0	2125	44690.51	0	44690.51	0.00%	21.48%	0.00	18.77
3.4y	12000	y	0	2125	44690.51	0	44690.51	0.00%	21.48%	0.00	18.77
3.5y	10400	y	0	2250	40427.11	0	40427.11	0.00%	19.43%	0.00	16.98
3.6y	5400	y	0	3500	18933.38	0	18933.38	0.00%	9.10%	0.00	7.95

2nd Story										W Load	
Wall No	**L (mm)**	**Direction**	**Yi(mm)**	**Xi(mm)**	**K (N/mm)**	**Kx (N/mm)**	**Ky (N/mm)**	**1kN x%**	**1kN y%**	**F (kN) Wx**	**F (kN) Wy**
2.1x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	8.27	
2.2x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	8.27	0.00
2.3x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	8.27	0.00
2.4x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	8.27	0.00
2.5x	4000	x	6600	0	11603.40	11603.40	0	3.35%	0.00%	2.37	0.00
2.6x	4000	x	5400	0	11603.40	11603.40	0	3.35%	0.00%	2.37	0.00
2.7x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	8.27	0.00
2.8x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	8.27	0.00
2.9x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	8.27	0.00
2.10x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	8.27	0.00
2.1y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	0.00	15.31
2.2y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	0.00	15.31
2.3y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	0.00	15.31
2.4y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	0.00	36.15
2.5y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	0.00	36.15
2.6y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	0.00	15.31
2.7y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	0.00	15.31
2.8y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	0.00	15.31

1st Floor										Wind	
Wall No	**L (mm)**	**Direction**	**Yi(mm)**	**Xi(mm)**	**K (N/mm)**	**Kx (N/mm)**	**Ky (N/mm)**	**1kN x%**	**1kN y%**	**F (kN) Wx**	**F (kN) Wy**
1.1x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	12.14	0.00
1.2x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	12.14	0.00
1.3x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	12.14	0.00
1.4x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	12.14	0.00
1.5x	4000	x	6600	0	11603.40	11603.40	0	3.35%	0.00%	3.49	0.00
1.6x	4000	x	5400	0	11603.40	11603.40	0	3.35%	0.00%	3.49	0.00
1.7x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	12.14	0.00
1.8x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	12.14	0.00
1.9x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	12.14	0.00
1.10x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	12.14	0.00
1.1y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	0.00	22.48
1.2y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	0.00	22.48
1.3y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	0.00	22.48
1.4y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	0.00	53.05
1.5y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	0.00	53.05
1.6y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	0.00	22.48
1.7y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	0.00	22.48
1.8y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	0.00	22.48

G Floor										Wind	
Wall No	**L (mm)**	**Direction**	**Yi(mm)**	**Xi(mm)**	**K (N/mm)**	**Kx (N/mm)**	**Ky (N/mm)**	**1kN x%**	**1kN y%**	**F (kN) Wx**	**F (kN) Wy**
G.1x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	16.01	0.00
G.2x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	16.01	0.00
G.3x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	16.01	0.00
G.4x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	16.01	0.00
G.5x	4000	x	6600	0	11603.40	11603.40	0	3.35%	0.00%	4.60	0.00
G.6x	4000	x	5400	0	11603.40	11603.40	0	3.35%	0.00%	4.60	0.00
G.7x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	16.01	0.00
G.8x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	16.01	0.00
G.9x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	16.01	0.00
G.10x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	16.01	0.00
G.1y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	0.00	29.64
G.2y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	0.00	29.64
G.3y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	0.00	29.64
G.4y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	0.00	69.96
G.5y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	0.00	69.96
G.6y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	0.00	29.64
G.7y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	0.00	29.64
G.8y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	0.00	
Σ (m)	**548.00**		**3.49**	**5.18**	**Σ**	**1218407.87**	**817045.99**				

Table 54: Distribution of Wind loads on walls.

Considering the Wind Loading:

4Story	Northern		Western	
	x	y	x	y
	N->S	W->E	N->S	W->E
	Fx CUM (kN)	Fy CUM (kN)	Fx CUM (kN)	Fy CUM (kN)
Roof	3.61	8.37	4.58	10.61
Third Floor	29.80	68.96	37.76	87.40
Second Floor	55.98	129.55	70.94	164.18
First Floor	82.16	190.14	104.12	240.97
Ground Floor	108.34	250.73	137.30	317.75

Table 55: Force distribution summary for 4 story building

2 Story	Northern		Western	
	x	y	x	y
	N->S	W->E	N->S	W->E
	Fx CUM (kN)	Fy CUM (kN)	Fx CUM (kN)	Fy CUM (kN)
Roof	3.39	7.88	4.25	9.88
First Floor	27.89	64.88	34.98	81.37
Ground Floor	52.39	121.88	65.71	152.86

Table 56: Force distribution summary for 2 story building

We can check the drift:

	Drift x (mm)	Drift y (mm)
Roof	0.03	0.05
Third Floor	0.21	0.42
Second Floor	0.20	0.81
First Floor	0.30	1.19
Ground Floor	0.40	1.57
Max Drift	0.40	1.57
Total Drift	1.14	4.03
Limit, L/300	**11.33**	**okay**

Table 57: Drift check from the Western wind 4 story building

The Following Table is considering the Earthquake Loading, split over 2 pages. It considers the loads per each wall.

3rd Story												Earthquake	
Wall No	**L (mm)**	**Direction**	**Yi(mm)**	**Xi(mm)**	**K (N/mm)**	**Kx (N/mm)**	**Ky (N/mm)**	**1kN x%**	**1kN y%**	**ky dx^2**	**kx dy^2**	**F (kN) Wx**	**F (kN) Wy**
3.1x	10400	x	5200	0	40427.11	40427.11	0	22.64%	0.00%	0	1.09315E+12	36.52	0.00
3.2x	6000	x	235	0	24424.63	24424.63	0	13.68%	0.00%	0	1348849940	22.07	0.00
3.3x	4400	x	5200	0	12813.24	12813.24	0	7.18%	0.00%	0	3.4647E+11	11.58	0.00
3.4x	4000	x	6600	0	11603.40	11603.40	0	6.50%	0.00%	0	5.05444E+11	10.48	0.00
3.5x	4000	x	5400	0	11603.40	11603.40	0	6.50%	0.00%	0	3.38355E+11	10.48	0.00
3.6x	10400	x	5200	0	40427.11	40427.11	0	22.64%	0.00%	0	1.09315E+12	36.52	0.00
3.7x	6000	x	235	0	24424.63	24424.63	0	13.68%	0.00%	0	1348849940	22.07	0.00
3.8x	4400	x	5200	0	12813.24	12813.24	0	7.18%	0.00%	0	3.4647E+11	11.58	0.00
3.1y	5400	y	0	6400	18933.38	0	18933.38	0.00%	9.10%	7.75511E+11	0	0.00	14.68
3.2y	10400	y	0	2250	40427.11	0	40427.11	0.00%	19.43%	2.04662E+11	0	0.00	31.34
3.3y	12000	y	0	2125	44690.51	0	44690.51	0.00%	21.48%	2.01806E+11	0	0.00	34.64
3.4y	12000	y	0	2125	44690.51	0	44690.51	0.00%	21.48%	2.01806E+11	0	0.00	34.64
3.5y	10400	y	0	2250	40427.11	0	40427.11	0.00%	19.43%	2.04662E+11	0	0.00	31.34
3.6y	5400	y	0	3500	18933.38	0	18933.38	0.00%	9.10%	2.31934E+11	0	0.00	14.68

2nd Story												Earthquake	
Wall No	**L (mm)**	**Direction**	**Yi(mm)**	**Xi(mm)**	**K (N/mm)**	**Kx (N/mm)**	**Ky (N/mm)**	**1kN x%**	**1kN y%**	**ky dx^2**	**kx dy^2**	**F (kN) Wx**	**F (kN) Wy**
2.1x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	14.19	0.00
2.2x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	0	582150415.4	14.19	0.00
2.3x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	0	145537603.9	14.19	0.00
2.4x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	14.19	0.00
2.5x	4000	x	6600	0	11603.40	11603.40	0	3.35%	0.00%	0	5.05444E+11	4.07	0.00
2.6x	4000	x	5400	0	11603.40	11603.40	0	3.35%	0.00%	0	3.38355E+11	4.07	0.00
2.7x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	14.19	0.00
2.8x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	0	582150415.4	14.19	0.00
2.9x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	0	145537603.9	14.19	0.00
2.10x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	14.19	0.00
2.1y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	3.81773E+12	0	0.00	11.35
2.2y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	3.33985E+11	0	0.00	11.35
2.3y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	95850254791	0	0.00	11.35
2.4y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	2.01806E+11	0	0.00	26.79
2.5y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	2.01806E+11	0	0.00	26.79
2.6y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	95850254791	0	0.00	11.35
2.7y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	3.33985E+11	0	0.00	11.35
2.8y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	3.81773E+12	0	0.00	11.35

1st Story												Earthquake	
Wall No	**L (mm)**	**Direction**	**Yi(mm)**	**Xi(mm)**	**K (N/mm)**	**Kx (N/mm)**	**Ky (N/mm)**	**1kN x%**	**1kN y%**	**ky dx^2**	**kx dy^2**	**F (kN) Wx**	**F (kN) Wy**
1.1x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	9.57	0.00
1.2x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	0	582150415.4	9.57	0.00
1.3x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	0	145537603.9	9.57	0.00
1.4x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	9.57	0.00
1.5x	4000	x	6600	0	11603.40	11603.40	0	3.35%	0.00%	0	5.05444E+11	2.75	0.00
1.6x	4000	x	5400	0	11603.40	11603.40	0	3.35%	0.00%	0	3.38355E+11	2.75	0.00
1.7x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	9.57	0.00
1.8x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	0	582150415.4	9.57	0.00
1.9x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	0	145537603.9	9.57	0.00
1.10x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	9.57	0.00
1.1y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	3.81773E+12	0	0.00	7.65
1.2y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	3.33985E+11	0	0.00	7.65
1.3y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	95850254791	0	0.00	7.65
1.4y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	2.01806E+11	0	0.00	18.07
1.5y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	2.01806E+11	0	0.00	18.07
1.6y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	95850254791	0	0.00	7.65
1.7y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	3.33985E+11	0	0.00	7.65
1.8y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	3.81773E+12	0	0.00	7.65

G Story												Earthquake	
Wall No	**L (mm)**	**Direction**	**Yi(mm)**	**Xi(mm)**	**K (N/mm)**	**Kx (N/mm)**	**Ky (N/mm)**	**1kN x%**	**1kN y%**	**ky dx^2**	**kx dy^2**	**F (kN) Wx**	**F (kN) Wy**
G.1x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	4.95	0.00
G.2x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	0	145537603.9	4.95	0.00
G.3x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	0	582150415.4	4.95	0.00
G.4x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	4.95	0.00
G.5x	4000	x	6600	0	11603.40	11603.40	0	3.35%	0.00%	0	5.05444E+11	1.42	0.00
G.6x	4000	x	5400	0	11603.40	11603.40	0	3.35%	0.00%	0	3.38355E+11	1.42	0.00
G.7x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	4.95	0.00
G.8x	10400	x	120	0	40427.11	40427.11	0	11.66%	0.00%	0	582150415.4	4.95	0.00
G.9x	10400	x	60	0	40427.11	40427.11	0	11.66%	0.00%	0	145537603.9	4.95	0.00
G.10x	10400	x	5200	0	40427.11	40427.11	0	11.66%	0.00%	0	1.09315E+12	4.95	0.00
G.1y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	3.81773E+12	0	0.00	3.96
G.2y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	3.33985E+11	0	0.00	3.96
G.3y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	95850254791	0	0.00	3.96
G.4y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	2.01806E+11	0	0.00	9.34
G.5y	12000	y	0	2125	44690.51	0	44690.51	0.00%	22.02%	2.01806E+11	0	0.00	9.34
G.6y	5400	y	0	2250	18933.38	0	18933.38	0.00%	9.33%	95850254791	0	0.00	3.96
G.7y	5400	y	0	4200	18933.38	0	18933.38	0.00%	9.33%	3.33985E+11	0	0.00	3.96
G.8y	5400	y	0	14200	18933.38	0	18933.38	0.00%	9.33%	3.81773E+12	0	0.00	3.96
Σ (m)	548.00		3.49	5.18	Σ	1218407.87	817045.99					407.47	407.47

Table 58: Distribution of Earthquake load on walls.

Level 3 Kx (N/mm)	Level 3 Ky (N/mm)	Level 2 Kx (N/mm)	Level 2 Ky (N/mm)	Level 2 Kx (N/mm)	Level 2 Ky (N/mm)	Level 1 Kx (N/mm)	Level 1 Ky (N/mm)	Ground Kx (N/mm)	Ground Ky (N/mm)
178536.76	208102.02	346623.70	202981.33	346623.70	202981.33	346623.70	202981.33	346623.70	202981.33

Table 59: Individual level stiffnesses

We obtain the drift for Earthquake loading

	Drift x (mm)	Drift y (mm)
Roof	0.90	0.78
Third Floor	1.59	1.36
Second Floor	1.05	1.80
First Floor	1.18	2.01
Max Drift	1.59	2.01
Total Drift	4.72	5.94
Limit, L/300	11.33	okay

Table 60: Drift check

Using the relative wall lengths, finding V* is possible

Floor	1x	2x	3x	4x	5x	6x	7x	8x	9x	10x
R	10.80	5.40	5.40	4.00	4.00	10.80	5.40	5.40	0	0
3	10.40	10.40	10.40	10.40	4.00	4.00	10.40	10.4	10.40	10.40
2	10.40	10.40	10.40	10.40	4.00	4.00	10.40	10.4	10.40	10.40
1	10.40	10.40	10.40	10.40	4.00	4.00	10.40	10.4	10.40	10.40

Table 61: Wall lengths

H (m)	Wall	1x	2x	3x	4x	5x	6x	7x	8x	9x	10x
13.6	R	36.52	22.07	11.58	10.48	10.48	36.52	22.07	11.58	0	0
10.2	3	50.72	25.22	19.98	24.67	14.56	40.60	36.26	19.98	14.19	14.19
6.8	2	60.29	34.80	29.55	34.25	17.30	43.34	45.83	29.55	23.76	23.76
3.4	1	65.24	39.74	34.50	39.19	18.72	44.77	50.78	34.50	28.71	28.71

Table 62: Cumulative forces calculated from earthquakes loads

Table 63: Moments calculated from earthquake loading

Wall	1x	2x	3x	4x	5x	6x	7x	8x	9x	10x
R M (kNm)	124.18	75.03	39.36	35.64	35.64	124.18	75.03	39.36	0.00	0.00
F3 M (kNm)	296.62	160.79	107.29	119.54	85.14	262.22	198.31	107.29	48.25	48.25
F2 M (kNm)	501.59	279.10	207.76	235.97	143.97	409.59	354.12	207.76	129.04	129.04
F1 M (kNm)	723.39	414.23	325.06	369.23	207.63	561.79	526.77	325.06	226.66	226.66

H	Floor	3y	4y	3y	4y
13.6	R	34.64	34.64	117.78	117.78
10.2	3	61.43	61.43	326.64	326.64
6.8	2	79.50	79.50	596.93	596.93
3.4	1	88.84	88.84	898.98	898.98

Table 64: Y direction Forces and Moments

Final Critical Shear and moment found as:

V^*= 88.84 kN

M^*= 898.98 kNm

Shear Wall Actions

The shear wall dimensions are tabulated based on the drawings:

Shear wall dimensions			Wall 1
t_{eff} (mm)	**L (mm)**	**H (mm)**	**t_p (mm)**
90	10400	3400	125

Table 65: Shear wall Dimensions

CLT Shear Wall (In Plane bending)

$$I = \frac{d_o b^3}{12}$$

B_{eff} (mm)	**Panel**	**t_i (mm)**	**t_{eff} (mm)**	**a_i (mm)**	**E_i (MPa)**	**Ac (mm^2)**	**I_{eff} (mm^4)**	**EI_{eff} (Nmm^2)**
1000	CL3/125	45	90	40	8000	45000	2.9478E+11	2.358E+15

Table 66: Effective stiffness of CLT walls in plane with lateral loading

Therefore, the section bending capacity can be calculated as follows:

$$\phi M = \phi_b k_1 k_4 k_6 k_9 k_{12} f_b Z_{eff}$$

φ	**k_1**	**k_4**	**k_6**	**k_9**	**k_{12}**	**f'_b (MPa)**	**Z_{eff} (mm^3)**	**φM (KNm)**
0.85	1	1	1	1	1	14	1.734E+08	2063.46

Table 67: Analysis of the moment capacity in the direction of lateral loads

Check if greater then M* = true, Okay

1. **Shearing-off failure of the boards along a joint**

a) Calculate shear capacity along joints

$$\Phi fs = \phi\, k_1 4 k_4\, k_6\, f_{s,90}$$

φ	**k_1**	**k_4**	**k_6**	**$f_{s,90}$ (MPa)**	**φfs (MPa)**
0.8	1	1	1	1.2	0.96

Table 68: Shear capacity of joints

b) Calculate shearing off failure

$$\tau_0 = \frac{V^*}{A_0}$$

V* (KN)	**t_i (mm)**	**L (mm)**	**A_o (mm^2)**	**$\tau 0 = \tau 90$ (MPa)**	**Check**
88.84	45	10400	468000	0.000189829	0.000197739

Table 69: Checking if the wall is safe from shearing off failure

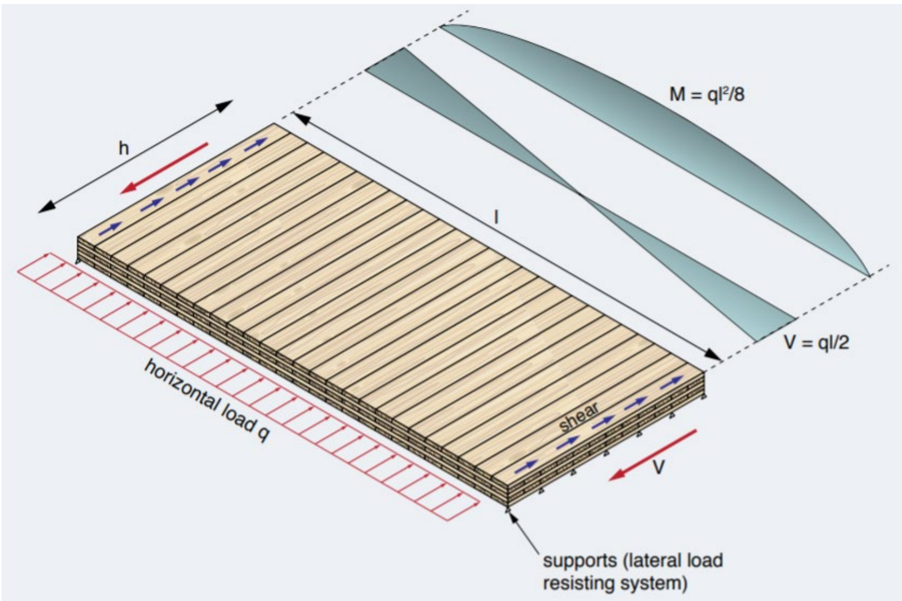
2. Calculate the internal Torsional stress

$$\tau_{TD} = \frac{3M_{TD}}{n_k a^3}$$

M_{td} (KNm)	n_s	n_f	n_k	a (mm)	τ_{TD}	Check
898.98	3	490	1470	140	0.668605343	0.696463899

Table 70: Checking the if the wall is safe from internal torsional stress

Diaphragm Actions



Resultant forces	
W1 (kN)	65.24
W2 (kN)	74.25
W3 (kN)	39.18
Total	178.67
Floor Length (m)	10.8
Line Load (KN/m)	16.54

Table 71: Calculating the Resultant line load on diaphragm

teff (mm)	135
beff (mm)	2000
L (mm)	5400

Table 72: Diaphragm Dimensions

M* (KNm)	241.21
V* (KN)	89.34

Table 73: Diaphragm Actions

Ei (MPa)	teff (mm)	beff (mm)	Ieff (mm4)	EIeff (Nmm2)
8000	135	2000	90000000000	7.2E+14

Table 74: Section properties of diaphragm

$$\phi M = \phi_b k_1 k_4 k_6 k_9 k_{12} f_b Z_{eff}$$

φ	k_1	k_4	k_6	k_9	k_{12}	f'$_b$ (MPa)	Z_{eff} (mm3)	φM (KNm)
0.85	1	1	1	1	1	14	9.000E+07	1071.00

Table 75: Shearing off failure along a joint

$$\Phi fs = \phi\ k_1 4 k_4\ k_6\ f_{s,90}$$

φs	k_1	k_4	k_6	$f_{s,90}$ (MPa)	φfs (MPa)
0.8	1	1	1	1.2	0.96

Table 76: Diaphragm shear check

$$\tau_0 = \frac{V^*}{A_0}$$

V* (KN)	ti (mm)	L (mm)	Ao (mm2)	τ0=τ90 (MPa)	Check
89.335	45	5400	243000	0.000367634	0.000383

Table 77: Shear stress along Joints

$$\tau_{TD} = \frac{3M_{TD}}{n_k a^3}$$

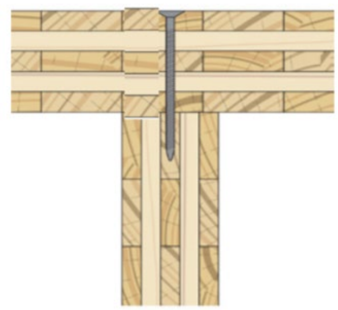
M_{td} (KNm)	n_s	n_f	n_k	a (mm)	τ_{TD}	Check
241.2045	3	1186	3558	140	0.074117	0.077205

Table 78: Torsional shear capacity

Connections

Screw Design – Withdrawal

Following (Spax EC5 V09.2015) design guide withdrawal resistance is determined by:



1. Withdrawal failure of thread in wall member
2. Head pull-through failure in floor member
3. Tensile failure of steel

Use Spax Fastener nom diameter 8mm Countersunk head with washer with a penetration depth of 200mm.

Withdrawal Failure						
neff	fax,k (N/mm2)	d1 (mm)	leff (mm)	p (kg/m3)	ϕ	fax,rk (KN)
1	12	8	200	465	0	20.08

Table 79: Capacity of single fastener withdrawal Failure

Head Pull Through Failure				
neff	p (kg/m3)	dh (mm)	fhead,k (N/mm2)	fax,rk (KN)
1	465	20	14	7.03

Table 80: Capacity of single fastener head pull through Failure

Screw Design – Shear Failure

The characteristic value of shear resistance to Eurocode 5 of a connection with SPAX fasteners is determined by comparison of 6 failure modes:

Failure mode (KN)						
a) Fv,Rk,a (KN)	b) Fv,Rk,b (KN)	c) Fv,Rk,c (KN)	d) Fv,Rk,d (KN)	e) Fv,Rk,e (KN)	f) Fv,Rk,f (KN)	Critical Shear Failure (KN)
36.78	11.31	16.16	13.26	3.01	3.87	3.01

Table 81: Results from the six shear failure modes

Design capacity in accordance with AS1720.1

Rdj = φ*k1*k13*k14*k17*n*Qk

Rdj (KN)	V* (KN)	Wall Length	V*/m	Minimum Spacing (m)	Adopted Spacing (mm)
4.58337	88.84	10.4	9.00	1.16	500

Table 82: Fastener Shear Capacity and minimum spacing in accordance with AS1720.1

Bracket Design – Shear Failure

φNdj = φ*k1*k13*k14*n*Qk

φ = 0.8

k1 = 1.14

k13 = 1

k14 = 1

Qk = 70KN - From connection manufacturer

(Rotho Titan TTF 200 selected)

Table : Fastener Shear Capacity and number of brackets.

2 Connections @ 5.2m minimum spacing required.

Bracket Design – Tension Failure

φNdj = φ*Qk

φ = 0.8

Qk = 31.4KN - From connection manufacturer

(Rotho Titan WHT 340 selected)

φNdj = 25.12 KN/connection

V* = 88.84KN

Therefore 4 Connections @ 2.6m minimum spacing required.

Design angle bracket fastener in shear (Rotho Titan TTF 200 selected)								
φ	k1	k13	k14	n	Qk (KN)	φNdj (KN)	V* (KN)	No Brackets
0.8	1.14	1	1	1	70	63.84	88.84	2

Appendix 1 External and Internal pressure coefficient calcs

External Pressure Coefficients

Determining what the coefficients are for each wall will be used to figure out the external pressure on each surface. The North and West direction must be considered for both buildings.

$$C_{fig,e} = C_{p,e} K_a K_{c,e} K_l K_p$$

Windward Wall <T5.2A>

h<25m C_{pe} =0.8 (taken as z=h)

<5.4.1>

Dimensions	4 Story	2 Story
Story height (m)	**13.6**	**6.8**
h (m)	13.835	7.035
d North (m)	28.5	26.6
d West (m)	10.8	10.8
b North (m)	10.8	10.8
b West (m)	28.5	26.6

Ratios of the height and breath of the buildings must be considered:

Direction	Building	h/d	d/b
Northern wind	4story	0.49	2.64
	2story	0.26	2.46
Western Wind	4story	1.28	0.38
	2story	0.65	0.41

Leeward Wall <T5.2B>

Coefficients for leeward wall are found considering the roof:

α = 5° < 10°

Direction	Building	Cpe
Northern wind	4story	-0.27
	2story	-0.28
Western Wind	4story	-0.5
	2story	-0.5

Side walls <T5.2C>

Coefficients for the side wall are found, where distances occur from windward edge of building.

4 Story		
Northern wind	Distance along surface (m)	Cpe
0-h	0-13.84	-0.65
h-2h	13.84-27.68	-0.5
2h-3h	27.68-28.5	-0.3
3h+		
		4 Story
Western Wind	Distance along surface (m)	Cpe
0-h	0-13.84	-0.65
	only goes up to 10.8	

2 Story		
Northern wind	**Distance along surface (m)**	**Cpe**
0-h	0-7..04	-0.65
h-2h	7.04-14.08	-0.5
2h-3h	14.08-21.12	-0.3
3h+	21.12-26.6	-0.2
Western Wind	**Distance along surface (m)**	**Cpe**
0-h	0-7..04	-0.65
h-2h	7.04-10.8	-0.5

Roof <T5.3A>

Roof coefficients are found, distances are occurring from windward edge.

4 Story			
Northern wind	**Distance (m)**	**Cpe**	**Cpe**
0-0.5h	0-6.92	-0.9	-0.4
0.5h-h	6.92-13.84	-0.9	-0.4
h-2h	13.84-27.68	-0.5	0
2h-3h	27.68-28.5	-0.3	0.1
3h+		-0.2	0.2
Western Wind	**Distance (m)**	**Cpe**	**Cpe**
0-0.5h	0-6.92	-0.9	-0.4
0.5h-h	6.92-13.84	-0.9	-0.4

2 Story			
Northern wind	**Distance**	**Cpe**	**Cpe**
0-0.5h	0-3.52	-0.9	-0.4
0.5h-h	3.52-7.04	-0.9	-0.4
h-2h	7.04-14.08	-0.5	0
2h-3h	14.08-21.12	-0.3	0.1
3h+	21.12-26.6	-0.2	0.2
Western Wind	**Distance**	**Cpe**	**Cpe**
0-0.5h	0-3.52	-0.9	-0.4
0.5h-h	3.52-7.04	-0.9	-0.4
h-2h	7.04-14.08	-0.5	0

<5.4.2>
Area reduction factor for roof and side walls is determined.
Ka = 1 conservative

<T5.5>

Action combination factor is determined from case b where 4 effective surfaces are utilised. Pressure from windward and leeward walls in comination with roof pressure and internal pressures.

Kce = 0.8 = Kci

<T5.6>
Kp=1 assume non permeable cladding or roof porosity

$$C_{fig,e} = C_{pe} \times 1 \times K_{c,e} \times 1 \times 1$$

Using the above coefficients, the aerodynamic shape factor for external pressure can be found and summarised in the tables below:

Windward wall

	Cpe	Cfige
All cases	0.8	**0.64**

Leeward Wall

		Cpe	Cfige
Northern wind	4story	-0.27	**-0.2144**
	2story	**-0.28**	**-0.2216**
Western Wind	4story	-0.5	**-0.4**
	2story	-0.5	**-0.4**

Side walls

4 Story			
Northern wind	**Distance along surface (m)**	**Cpe**	**Cfige**
0-h	0-13.84	-0.65	**-0.52**
h-2h	13.84-27.68	-0.5	**-0.4**
2h-3h	27.68-28.5	-0.3	**-0.24**
3h+			
4 Story			
Western Wind	**Distance along surface (m)**	**Cpe**	**Cfige**
0-h	0-13.84	-0.65	**-0.52**
	only goes up to 10.8		**0**

2 Story			
Northern wind	**Distance along surface (m)**	**Cpe**	**Cfige**
0-h	0-7.04	-0.65	**-0.52**
h-2h	7.04-14.08	-0.5	**-0.4**
2h-3h	14.08-21.12	-0.3	**-0.24**
3h+	21.12-26.6	-0.2	**-0.16**
2story			
Western Wind	**Distance along surface (m)**	**Cpe**	**Cfige**
0-h	0-7.04	-0.65	**-0.52**
h-2h	7.04-10.8	-0.5	**-0.4**

Roof

4 Story					
Northern wind	**Distance along surface (m)**	**Cpe**	**Cpe**	**Cfige**	**Cfige**
0-0.5h	0-6.92	-0.9	-0.4	**-0.72**	**-0.32**
0.5h-h	6.92-13.84	-0.9	-0.4	**-0.72**	**-0.32**
h-2h	13.84-27.68	-0.5	0	**-0.4**	**0**
2h-3h	27.68-28.5	-0.3	0.1	**-0.24**	**0.08**
3h+					
Western Wind	**Distance along surface (m)**	**Cpe**	**Cpe**	**Cfige**	**Cfige**
0-0.5h	0-6.92	-0.9	-0.4	**-0.72**	**-0.32**
0.5h-h	6.92-13.84	-0.9	-0.4	**-0.72**	**-0.32**
h-2h					
2h-3h					
3h+					

2 Story					
Northern wind	**Distance along surface (m)**	**Cpe**	**Cpe**	**Cfige**	**Cfige**
0-0.5h	0-3.52	-0.9	-0.4	**-0.72**	**-0.32**
0.5h-h	3.52-7.04	-0.9	-0.4	**-0.72**	**-0.32**
h-2h	7.04-14.08	-0.5	0	**-0.4**	**0**
2h-3h	14.08-21.12	-0.3	0.1	**-0.24**	**0.08**
3h+	21.12-26.6	-0.2	0.2	**-0.16**	**0.16**
Western Wind	**Distance along surface (m)**	**Cpe**	**Cpe**	**Cfige**	**Cfige**
0-0.5h	0-3.52	-0.9	-0.4	**-0.72**	**-0.32**
0.5h-h	3.52-7.04	-0.9	-0.4	**-0.72**	**-0.32**
h-2h	7.04-14.08	-0.5	0	**-0.4**	**0**
2h-3h					
3h+					

Internal Pressure Coefficients

Determining the internal pressure coefficients in conjunction with 4 cases considered can determine the internal pressure. Cases include the whole building sealed, all openings open, and each side open while others are closed.

<T5.5>

k_{ci} = 0.8

Case b as in External pressure.

4 Story Northern Wind

The combined areas of the openings were found per floor then per side of the building:

Opening area per floor	**North (m^2)**	**East (m^2)**	**South (m^2)**	**West (m^2)**
G	32.91	26.48	23.46	5.6
1	25.665	12	25.665	20.08
2	25.665	12	25.665	20.08
3	15.9	13.075	15.9	6.675

Building side	**Total area of openings (m^2)**
Northern Side	90.69
East Side	63.555
South Side	94.9
West side	52.435

The individual cases were considered as to which openings were sealed or open.

Case 1: All closed

Consider all sealed, building effectively sealed and non opening windows

C_{pi}	-0.2	0

Case 2: All Openinings Open

Consider 4 sides opened

Dominant: North

	N/E		N/W		N/S	
Ratio	1.426953033		1.729569944		1.046421877	
Table values	-0.3	0	-0.3	0	-0.3	0
Interpolated values Cpi	**-0.287**	**-0.113**	**-0.278**	**-0.197**	**-0.299**	**-0.011**
$C_{pi} = C_{pe}$	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27

Case 3: North Open, others closed

Cpi =	**Cpe**	**0.8**

Case 4: East Open, others closed

Cpi =	**Cpe**	**-0.5**

Case 5: West Open, others closed

Cpi =	**Cpe**	**-0.5**

Case 6: South Open, others closed

Cpi =	**Cpe**	**-0.27**

The coefficients can be used to find the external aerodynamic shape factor:

$C_{figi} = C_{p,i}\, k_{c,i}$

Aerodynamics shape factor for external pressures:

Northern Wind		**Acting location**	**Cfig i 1**	**Cfig i 2**
Case 1	None	Surface	-0.16	0
	N/E	Surface	-0.2296	-0.0904
	N/W	Surface	-0.2224	-0.1576
Case 2	**N/S**	Surface	-0.2392	-0.0088
Case 3	N/0	Surface	0.64	0
	E/0	0-h	-0.52	0
		h-2h	-0.4	0
Case 4		2h-3h	-0.24	0
	W/0	0-h	-0.52	0
		h-2h	-0.4	0
Case 5		2h-3h	-0.24	0
Case 6	S/0	Surface	-0.216	0

This procedure is now followed for the other wind directions producing the largest site wind speeds for both buildings.

4 Story Western Wind

Case 1: No openings open

Consider all sealed, building effectively sealed and non opening windows

C_{pi}	-0.2	0

Case 2: All Openinings Open

Consider 4 sides opened

Dominant: North

	N/E		N/W		N/S	
Ratio	1.426953033		1.729569944		1.046421877	
Table values	-0.1	0.2	-0.1	0.2	-0.1	0.2
Interpolated values Cpi	-0.3576	-0.2184	-0.4416	-0.3744	-0.2512	-0.0208
$C_{pi} = C_{pe}$	-0.65	-0.65	-0.65	-0.65	-0.65	-0.65

Case 3: North Open

Cpi =	**Cpe**	**-0.65**

Case 4: East Open

Cpi =	**Cpe**	**-0.5**

Case 5: West Open

Cpi =	**Cpe**	**0.8**

Case 6: South Open

Cpi =	**Cpe**	**-0.65**

$C_{figi} = C_{p,i} \, k_{c,i}$

Summary

Western Wind		Acting location	Cfig i 1	Cfig i 2
Case 1	None	Surface	-0.16	0
Case 2	**N/E**	0-h	-0.3576	-0.2184
	N/W	0-h	-0.4416	-0.3744
	N/S	0-h	-0.2512	-0.0208
Case 3	N/0	0-h	-0.52	
		h-2h	-0.4	
		2h-3h	-0.24	
Case 4	E/0	surface	-0.4	0
Case 5	W/0	surface	0.64	0
Case 6	S/0	0-h	-0.52	
		h-2h	-0.4	
		2h-3h	-0.24	

2 Story Northern Wind

Opening area	North (m^2)	East (m^2)	South (m^2)	West (m^2)
G	17.83	18.32	23.49	20.715
1	17.83	11.6	23.49	20.715

Building Side	Total area of openings (m^2)
Northern Side	35.66
East Side	33.77
South Side	46.98
West Side	41.43

Case 1: No openings open

Consider all sealed, building effectively sealed and non opening windows

C_{pi}	-0.2	0

Case 2: All Openinings Open

Consider 4 sides opened

Dominant: South

	S/E		S/W		S/N	
Ratio	1.3911756		1.133960898		1.317442513	
Table values	-0.3	0	-0.3	0	-0.3	0
Interpolated values Cpi	**-0.287**	**-0.158**	**-0.297**	**-0.036**	**-0.293**	**-0.089**
$C_{pi} = C_{pe}$	-0.277	-0.277	-0.277	-0.277	-0.277	-0.277

Case 3: North Open

Cpi =	**Cpe**	**0.8**

Case 4: East Open

Cpi =	**Cpe**	**-0.5**

Case 5: West Open

Cpi =	**Cpe**	**-0.5**

Case 6: South Open

Cpi =	**Cpe**	**-0.27**

Summary:

Northern Wind		Acting location	Cfig i 1	Cfig i 2
Case 1	None	Surface	-0.16	0
Case 2	**N/E**	Surface	-0.2328	-0.0904
	N/W	Surface	-0.2376	-0.1576
	N/S	Surface	-0.2344	-0.0088
Case 3	N/0	Surface	0.64	0
Case 4	E/0	0-h	-0.52	0
		h-2h	-0.4	0
		2h-3h	-0.24	0
Case 5	W/0	0-h	-0.52	0

		h-2h	-0.4	0
		2h-3h	-0.24	0
Case 6	S/0	Surface	-0.216	0

2 Story Western Wind

Case 1: No openings open

Consider all sealed, building effectively sealed and non opening windows

C_{pi}	-0.2	0

Case 2: All Openings Open

Consider 4 sides opened

Dominant: South

	S/E				**S/W**				**S/N**			
Ratio	1.3911756				1.133960898				1.317442513			
Table values	-0.3	0	-0.3	0	-0.3	0	-0.3	0	-0.3	0	-0.3	0
Interpolated values Cpi	**-0.499**	**-0.113**	**-0.414**	**-0.285**	**-0.278**	**-0.197**	**-0.326**	**-0.65**	**-0.299**	**-0.011**	**-0.364**	**-0.16**
$C_{pi} = C_{pe}$	-0.65	-0.65	-0.5	-0.5	-0.65	-0.65	-0.5	-0.5	-0.65	-0.65	-0.5	-0.5

Case 3: North Open

Cpi =	**Cpe**	**-0.5**

Case 4: East Open

Cpi =	**Cpe**	**-0.5**

Case 5: West Open

Cpi =	**Cpe**	**0.8**

Case 6: South Open

Cpi =	**Cpe**	**-0.65**

Summary:

Western Wind		**Acting location**	**Cfig i 1**	**Cfig i 2**
Case 1	None	Surface	-0.16	0
Case 2	**S/E**	0-h	-0.3496	-0.2032
		h-2h	-0.3312	-0.228
	S/W	0-h	-0.276	-0.0672
		h-2h	-0.2608	-0.052
	S/N	0-h	-0.3272	-0.1608
		h-2h	-0.2912	-0.128
Case 3	N/0	0-h	-0.52	0
		h-2h	-0.4	0
		2h-3h	-0.24	0
Case 4	E/0		-0.4	0
Case 5	W/0		0.64	0

Case 6	S/0	0-h	-0.52	0
		h-2h	-0.4	0
		2h-3h	-0.24	0