LOT 49 VICTORIA STREET.

100 YEAR LIFE CYCLE
EMBODIED ENERGY
ADAPTIVE RE-USE

Modular Net Zero Construction

ABOUT

Modular Net Zero Mixed Use Construction
Lot 47-49 Victoria Street Midland. Western Australia.

The aim of this project was to develop a modular construction design that focusses on adaptive reuse of embodied materials and eliminating waste through typical 50-100 year building lifecyles.

Typically the presumed outcome of reducing co2 emissions is to implement solar power generation, water harvesting strategies through roof collection and community gardens creating a hollistic community. However, these approaches only reduce Australia's direct Co2 emissions by 1.9%. In comparison, the building and construction industry currently contributes 18.1% of Australia's total cabon emissions through embodied energy of materials during the construction and demolition phases (Yu, M. Et. Al. 2017).

The proposal utilises simple prefabricated components to create an adaptable and customisable building. Prefabricated modular designs are selected by the owner, then lowered into a concrete prefab structure. The modules can be placed side by side to expand or reduce apartment sizes depending on the owners requirements and are fully contained. Due to the unique design, as material options get better in the future, new owners adding their modules to the building can opt for CLT walls and framing, or update insulation and services to the highest effency available. Existing owners can update services or even renovate their modules at the 20, 50, 100 year life cycles. This encourages continued use of existing modules, structure and building services to reduce construction waste from embodied materials that would typically occur if the entire building was demolished for a larger apartment complex.

12 apartments ranging from 1 x 1 through to 3 x 2 options are marketed towards all age groups between 18 - 60+.

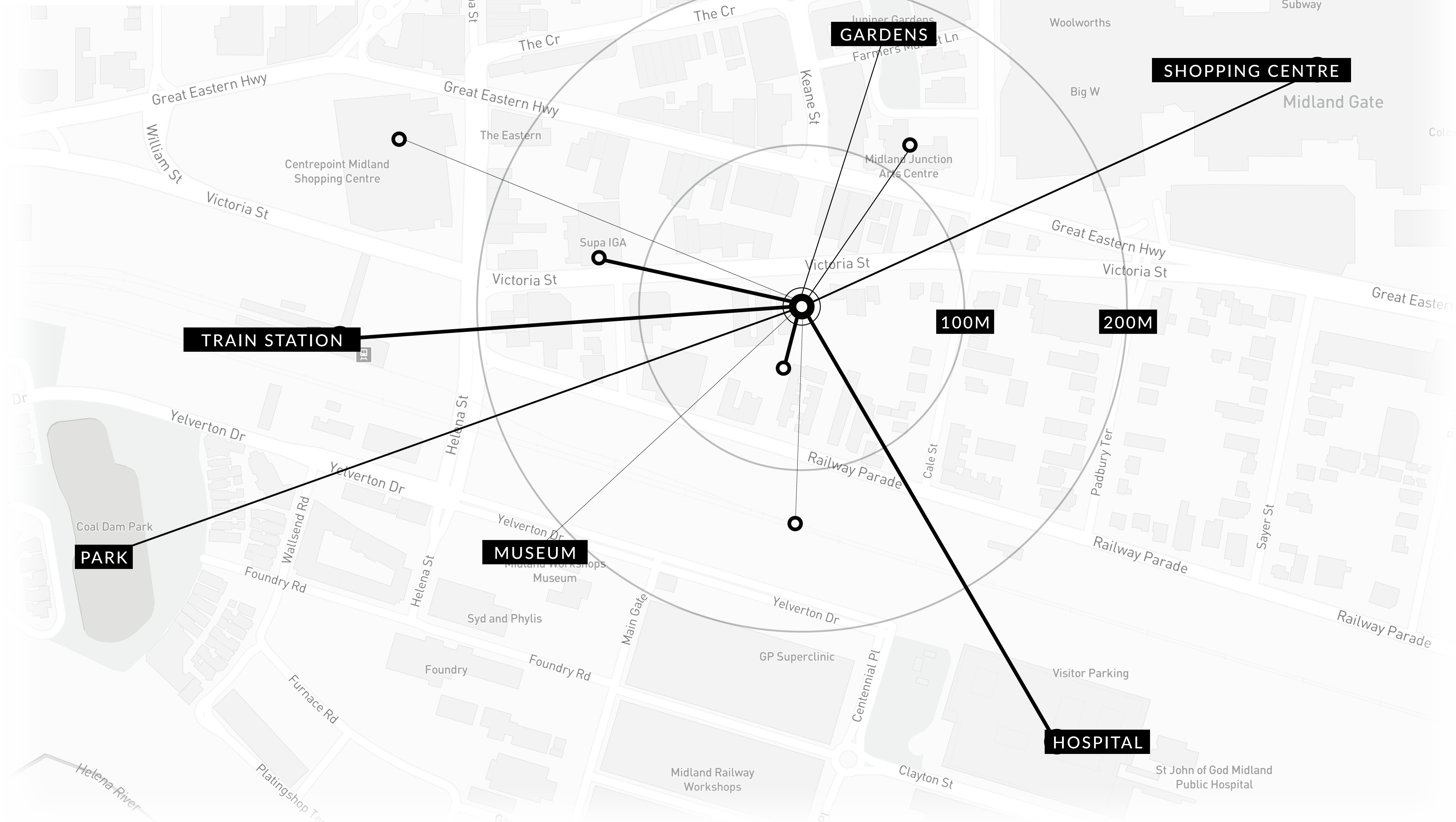
This proposal has been designed and prepared by: Cameron Atkins
M.Arch Curtin University 5th Year PRAXIS Project.

CONTENTS

SITE

MIDLAND, WA.

Walkability to Key Services and Public Transport



SCALE 1:1000

This proposal offers midland city a unique apartment concept featuring a standardised modular construction typology that could be applied to any vacant lot in the city.

Located on lot 47-49 Victoria Street, Midland. The site offers a new road and footpath connection through the city centre that connects the now underway redevelopment of midland station to the site. As the train station is only 300m away, this connection promotes walkability within the city, and minimises car dependency with shops within 150m walking distance, along with limited on-site carparking.

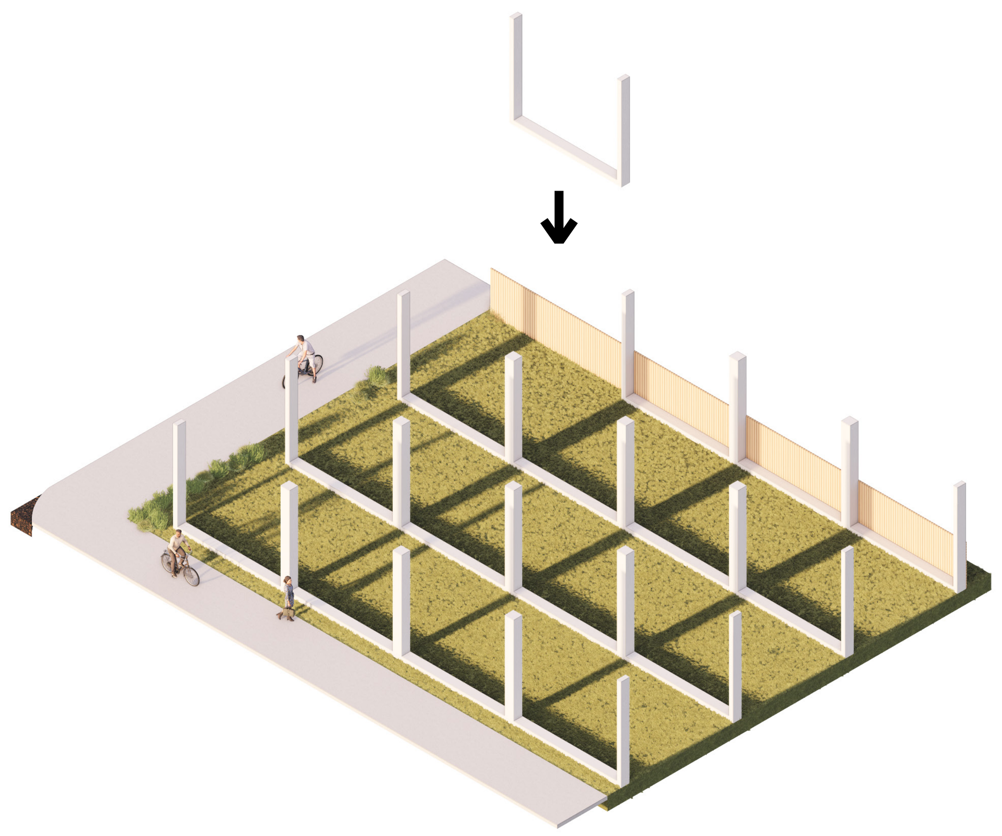
Midland city council stipulates that up to 3 levels can be built before setback rules require the 4th level to be setback by 3 metres from the boundary line. This has been achieved by the flexible modular deisgn that allows units to be pushed back by 5 metres into the frame behind and connect to all vertical services and maintain structural integrity.

Midland offers a rich construction history with one of Perth's most well known brick companies based in this area, Midland Brick. The significant economic effect of the brick laying industry in Perth fundamentally changed the construction typology in Western Australia to primarily using brick wall construction in comparison to the Eastern States with a mixture of Steel and timber constructed homes.

This project explored the possibility of utilisng brick materials within the apartment design, but due to the lightweight & transportable requirements of the design, it was not structurally sound or financially feasable to increase the weight of the modules.

Therefore, this apartment complex highlights a significant cultural adjustment to the way things have previously been. With a strong focus on embodied energy throughout the entire lifecyle of a project. Being constructed from steel and timber signifies the changing future of design, and with it a new way to reduce construction waste.

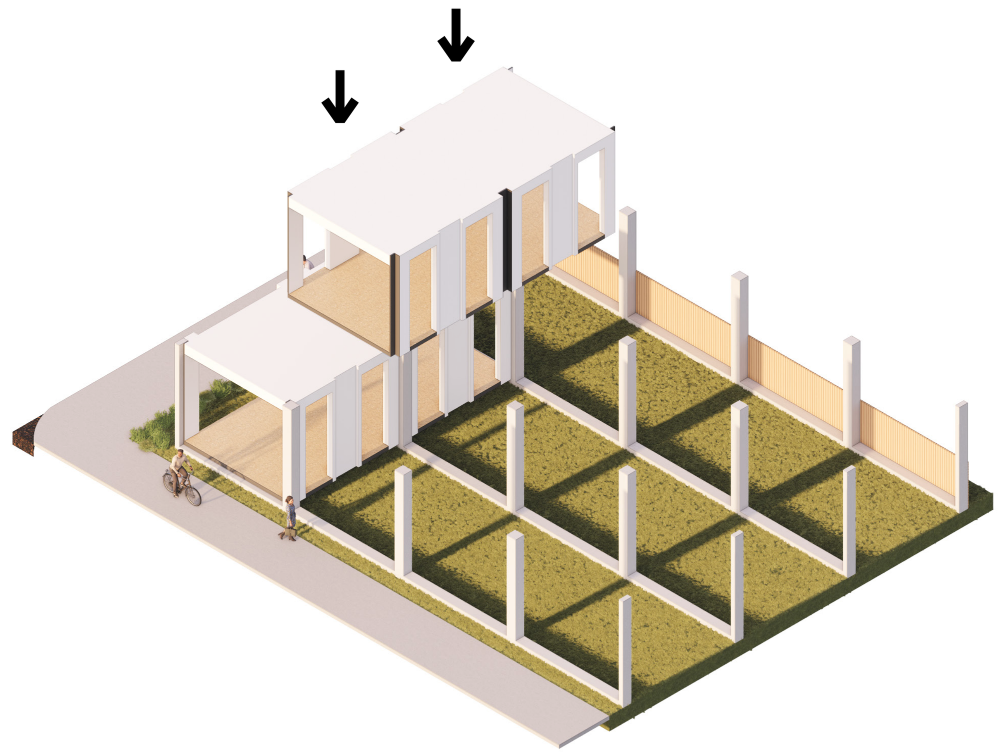
CONCEPT



BASE FRAMING LAID

Prefabricated super structure made from either Steel, CLT or concrete is laid on the vacant lot, side by side with a 5-metre gap between rows to lock the modules in. The structural frame also acts as the footings on the site, as the modules will be elevated from the ground, sittiting on the frame.

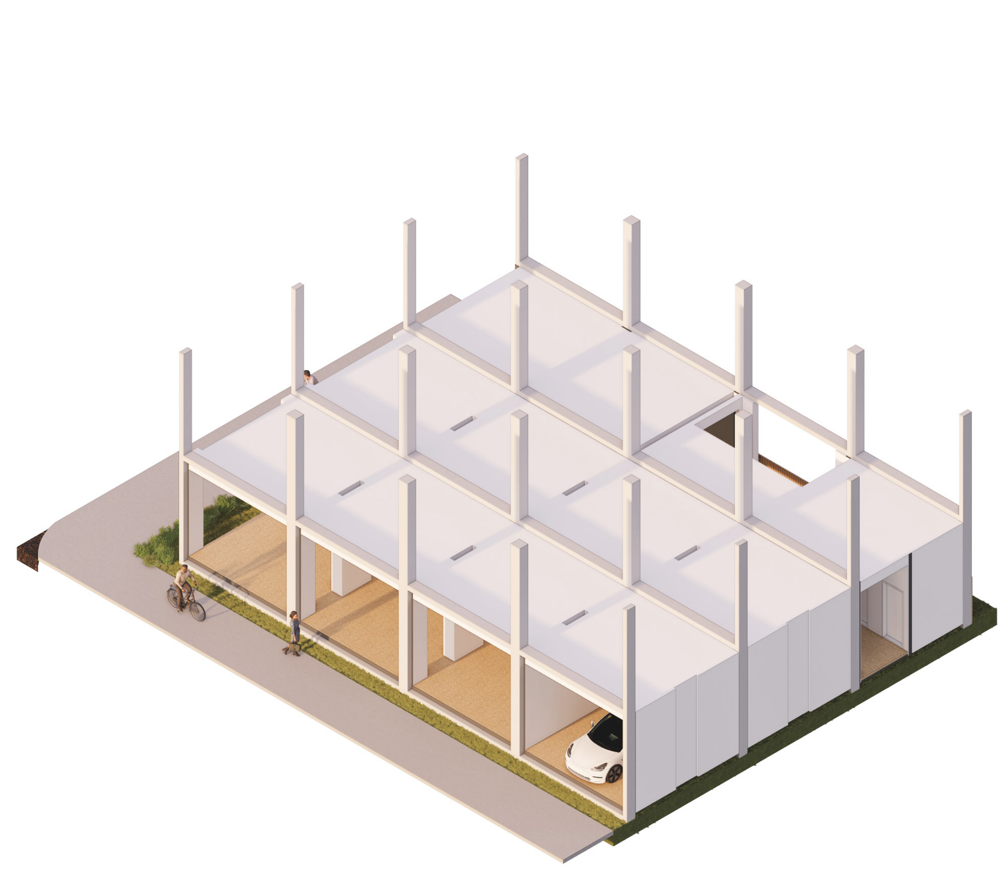
Although Steel has higher embodied energy, it was specifically chosen as it allows future vertical expansion without major works. This is due to the compression strength, considerably longer lifecycle and simple maintanence in comparision with timber CLT beams for a 100-year lifecycle.



MODULES CRANED IN

Prefabricated modules are craned in over the framing and lowered in place using the frames as guides. Horizontal strength is created using the modules after they have been locked in place using compression strength transfer through each module.

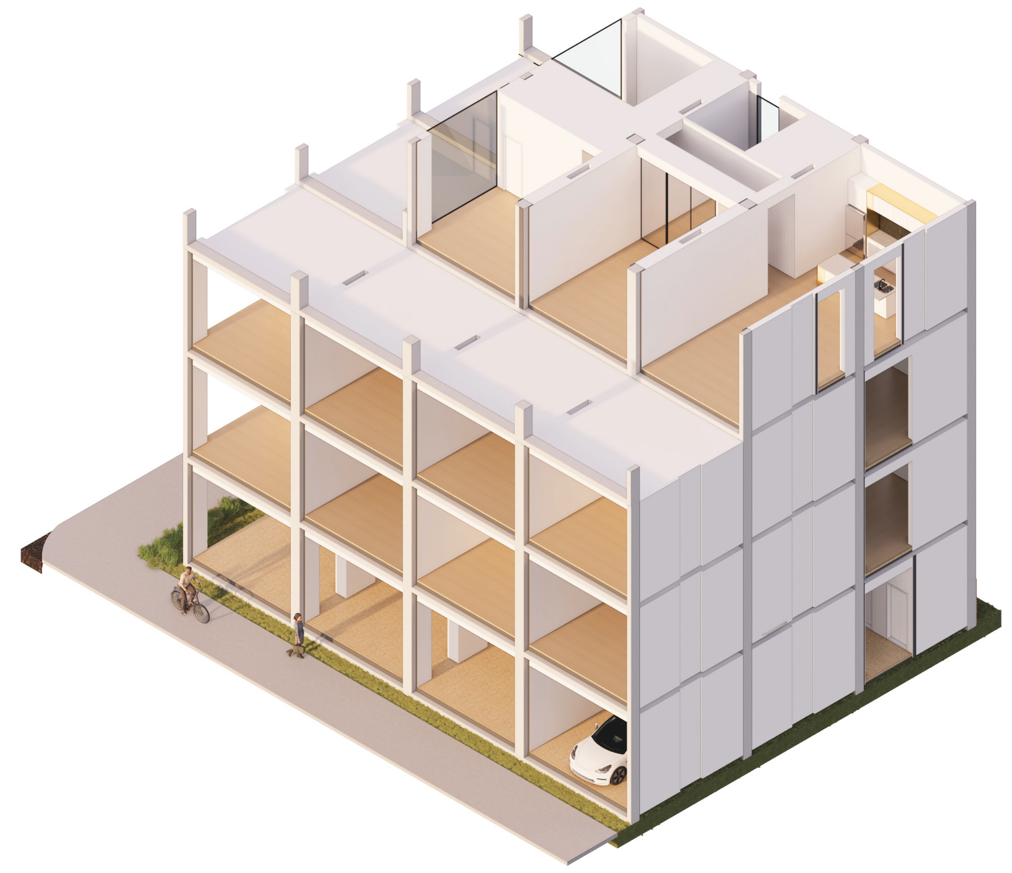
Modules can also be swapped or shared by residents in the building. This encourages a live building that will be used at or near capacity. Unlike typical Australian homes, where retirees are often still living in large family homes with unocupied rooms, those modules with unused rooms can now be sold or exchanged.



FRAMING CONTINUED

For additional levels, the same prefabricated superstructure supports are used to expand the vertical and horizontal size of the structure depending on the number of modules required.

Once modules have been placed within the frame, the structural integrity has been formed.



SET BACK CODE + SERVICES

Modules can be set back in the frame to abide council set back codes by 5 metres at each increment. Allowing unique designs to form on awkward lots and reduce overshadowing.

Modules still connect to the vertical services due to the 4 key connections for each module. If any service point is not functional, they can be re-directed to one of the other 3 available.

UNIQUE FACADES ADDED

Unique facades are chosen by the owner, then craned in on the front of the modules, attached to the vertical superstructure supports, eliminating typical repetitive design on apartment buildings. Facades have been designed to be a maximum of 10 and 20% the length of a module to ensure succesful cantilevering regardless of the module type. Facades can also be swapped with other residents in the future as owners or circumstances change.

ROOF + BALCONIES

Modules can have roof designs attached on top where the height of the apartments has been finished to create unique structures. These roof modules can be removed at a later date and replaced with vertical supports and more apartments. Aiding in housing shortages, or as local demand increases. These rooftop apartments can also be shifted up the building to reduce construction waste, where demolishion would typically occur.

FUTURE EXPANSION

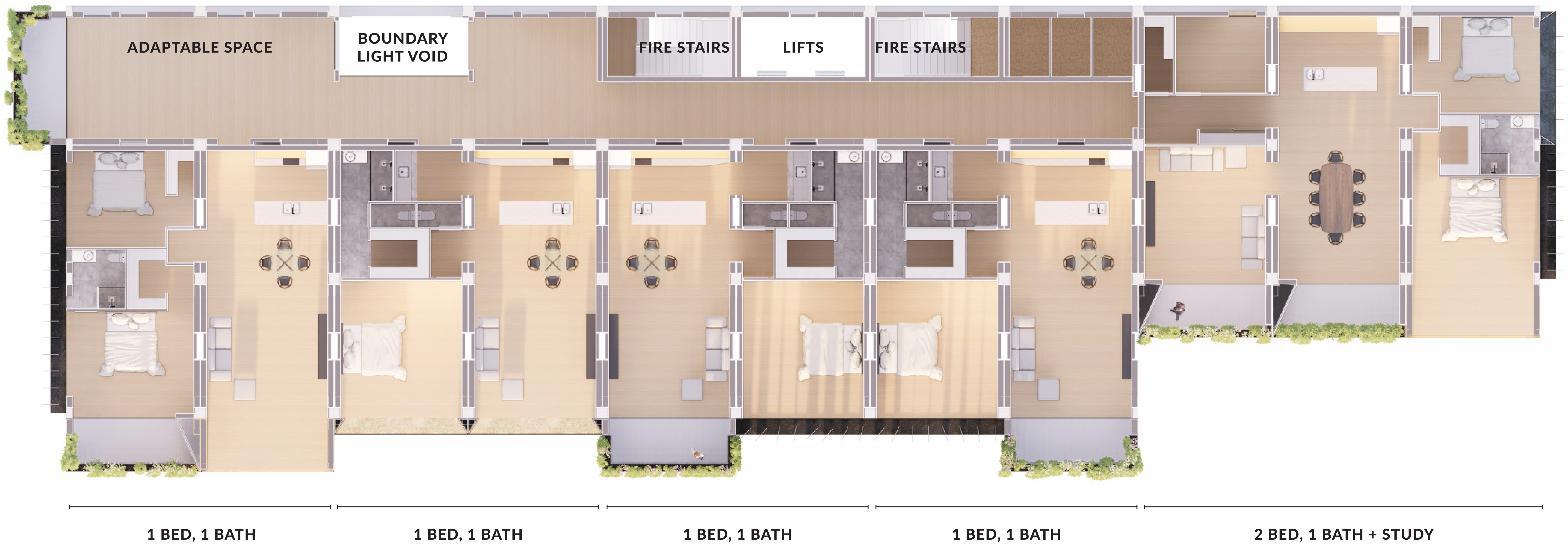
Future expansion is possible at any point by removing the top level roof modules and apartments (without ceilings) and replacing them with new standard modules as required. The compression strength framing was specifically engineered to allow additional weight from future expansion without any major works. Aiding in housing shortages, or as local demand increases.

ADAPTIVE RE-USE

The rooftop apartments and roof modules that were removed previously will now be shifted up the building to the new top floor. Ensuring residents maintain their premium views, and keep their existing apartments. Currently, entire buildings are typically demolished to construct larger apartment buildings. Where as this design allows apartments to be added, eliminating construction waste from embodied materials that are demolished, ensuring a 100 year module life cycle is achieved.

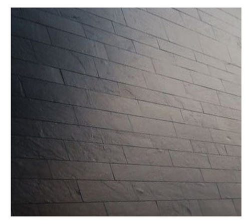
GROUND FLOOR

FIRST FLOOR



SCALE 1:100

SECOND FLOOR



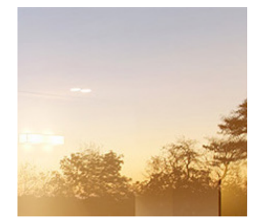
SLATE FACADE
100+ YEAR LIFE CYCLE
LOW EMBODIED CO2
SOUTH AUS. MINED
100% RECYCLABLE

EXT. TILES
100+ YEAR LIFE CYCLE
LOW EMBODIED CO2
WEST AUS. MADE
PORCELAIN TILE
100% RECYCLABLE

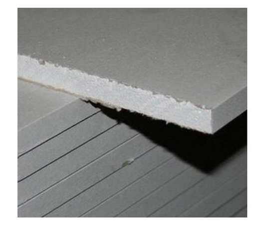
BRASS FACADE
1000+ YEAR LIFE CYCLE
LOW EMBODIED CO2
WEST AUS. MINED
70% RECYCLABLE

2 BED, 1 BATH | 1 BED, 1 BATH | 2 BED, 2.5 BATH + STUDY | 2 BED, 2 BATH

WOOD LOUVRE
50+ YEAR LIFE CYCLE
LOW EMBODIED CO2
WEST AUS. MINED
100% RECYCLABLE

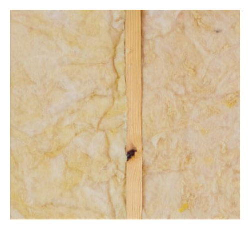


DBL. GLAZED
WINDOW GLASS
1000+ YEAR LIFE CYCLE
LOW EMBODIED CO2
WEST AUS. MINED
100% RECYCLABLE



EXT. GYPROCK
WALL FINISH
70+ YEAR LIFE CYCLE
LOW EMBODIED CO2
WEST AUS. MINED
100% RECYCLABLE

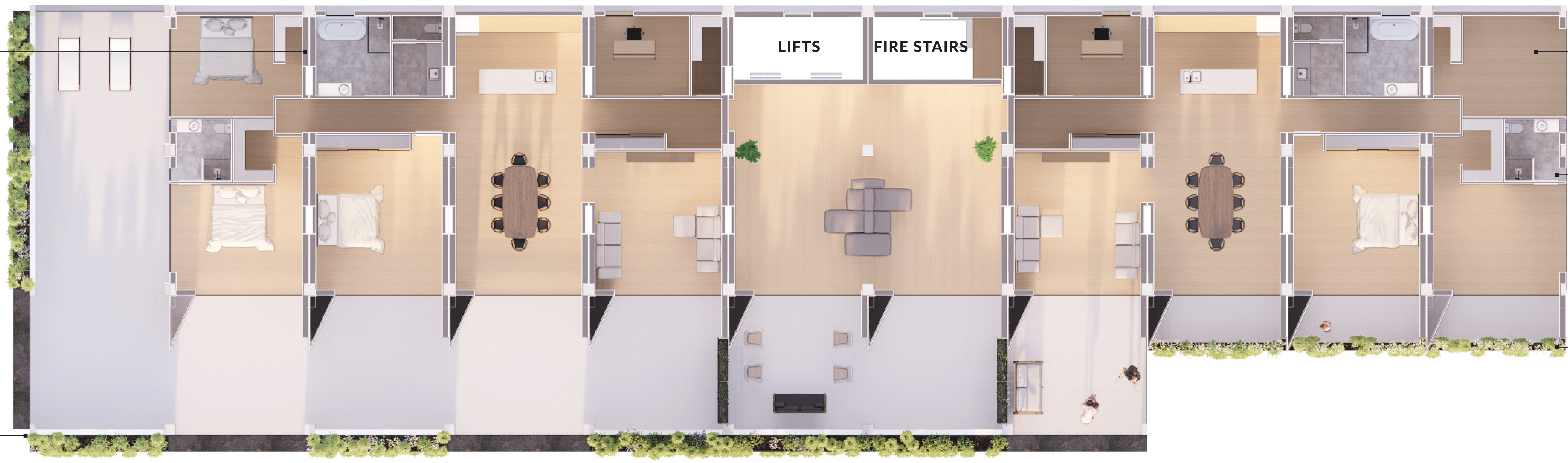
THIRD FLOOR



INSULATION
BRADFORD GOLD R4.0
70+ YEAR LIFE CYCLE
LOW EMBODIED CO2
AUSTRALIAN MADE
100% RECYCLABLE

VEGGIE GARDEN
2+ YEAR LIFE CYCLE
NO EMBODIED CO2
100% RECYCLABLE

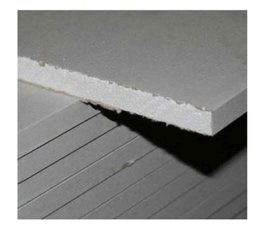
STEEL / CLT
SUPER STRUCTURE
100+ YEAR LIFE CYCLE
LOW EMBODIED CO2
WEST AUS. MINED
100% RECYCLABLE



3 BED, 2 BATH + STUDY | COMMUNITY SPACE | 3 BED, 2 BATH + STUDY

TIMBER FLOOR
BLACKBUTT SOLID TIM.
100+ YEAR LIFE CYCLE
LOW EMBODIED CO2
VIC, AUS. MINED
100% RECYCLABLE

INT. TILES
100+ YEAR LIFE CYCLE
LOW EMBODIED CO2
WEST AUS. MADE
PORCELAIN TILE
100% RECYCLABLE

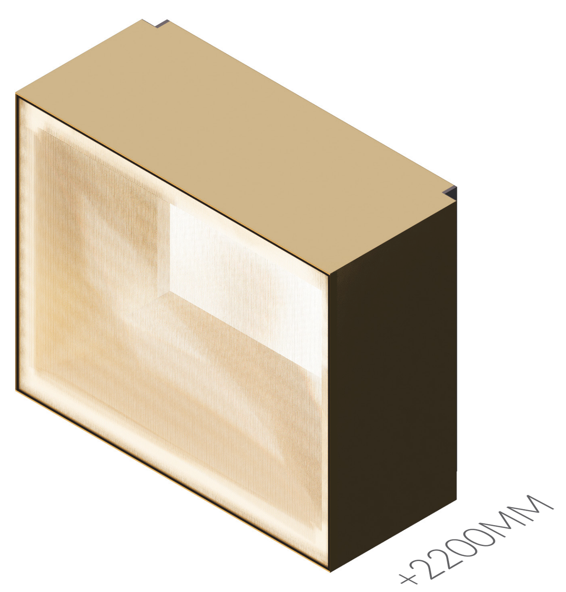


AQUA GYRPOCK
WATER PROOF
50+ YEAR LIFE CYCLE
LOW EMBODIED CO2
WEST AUS. MINED
100% RECYCLABLE

SCALE 1:100

FACADE OPTIONS

Facade options vary depending on the unique design or purpose the owner is intending to achieve. Each option fits perfectly in the space available and will not clash or interfere with a neighbouring facade. This allows full creative freedom over the final design outcome of the structure. The embossed glass adds an additional 2.2 metres of internal space to each module, but sacrifices louvre shading or a balcony. The dynamic louvre allows individual control over the sun penetration into the module and in comparison the multiple balcony options offer a private vegie garden, and privacy from a nosy next door neighbour.



EMBOSSED GLASS

Stunning diamond embossed glass wrapped in brass that offers full privacy internally + reflecting light to create an immersive view out.

DYNAMIC LOUVRE

Customisable sun-shading & weather protection all year round. Finished in natural timber for a weathered look.

SLATE GLASS

Standard facade option that offers a full height window with low embodied slate finish. Internal window coverings are recommended.

BALCONY & VEGGIE GARDEN

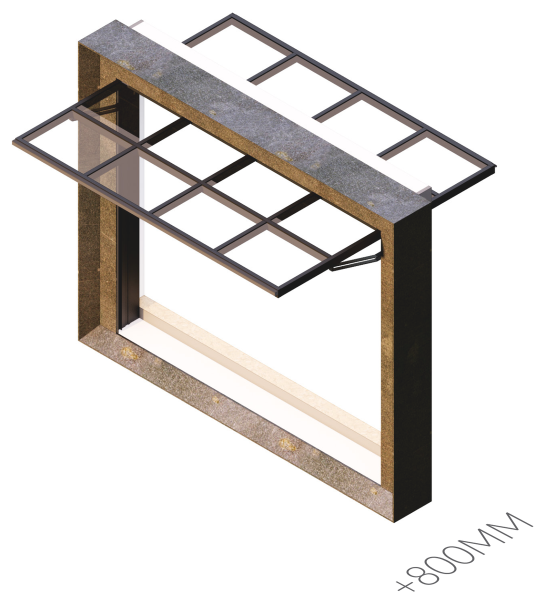
With 180 degree views, the slate balcony prioritises a private veggie garden experience and large windows.

SLATE & BRASS BALCONY

With 90 degree views, and a private veggie garden, the brass shield creates privacy from neighbours and creates visual contrast.

SLATE & GARDEN RAILING

Unique railing with dual stacked garden beds to compliment the slate range of facades.

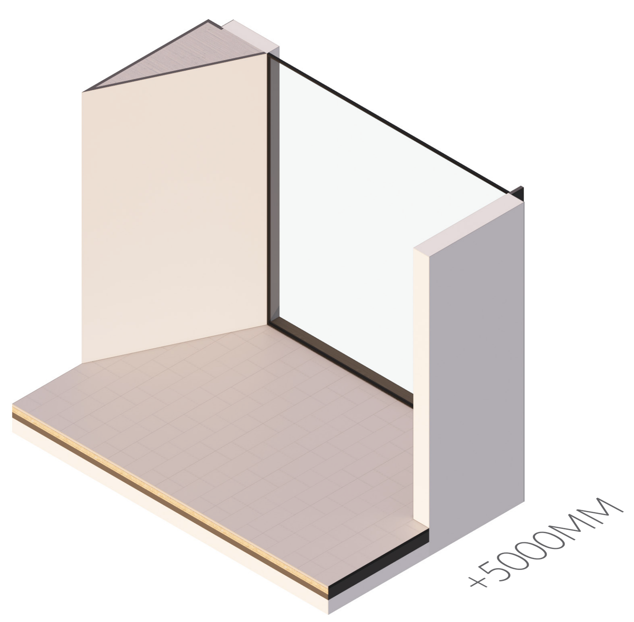


TILT UP DOOR (UP)

When the door is up, it acts as a natural canopy for ground floor retail spaces protecting from light rain.

TILT UP DOOR (DOWN)

Designed for ground floor retail, the tilt up door utilises a built in motor and solid pane of glass for a unique connection.

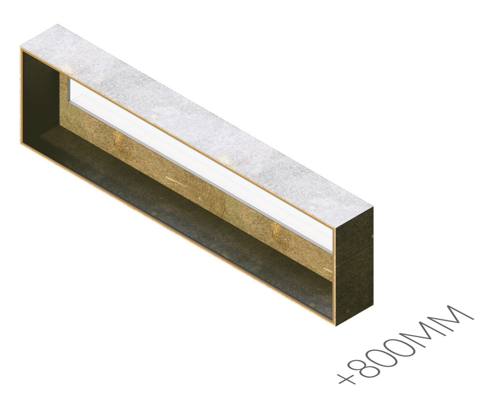


SET BACK BALCONY [ONLY]

For setback requirements, these 5000mm x 5000mm modules are balconies that utilise railing facades at the end. Filling the gap to utilised roof space that would otherwise be wasted.

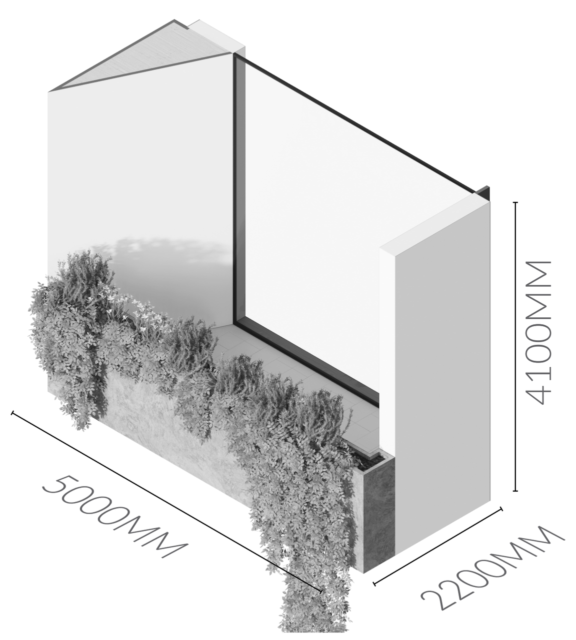
MATTE WHITE BALCONY

With 90 degree views, and a private veggie garden, the matte white shields create privacy from nosy neighbours.



SLATE & GLASS RAILING

Unique 1000mm (H) railing with a low glass window to compliment the slate range of facades.



FACADE DIMENSIONS

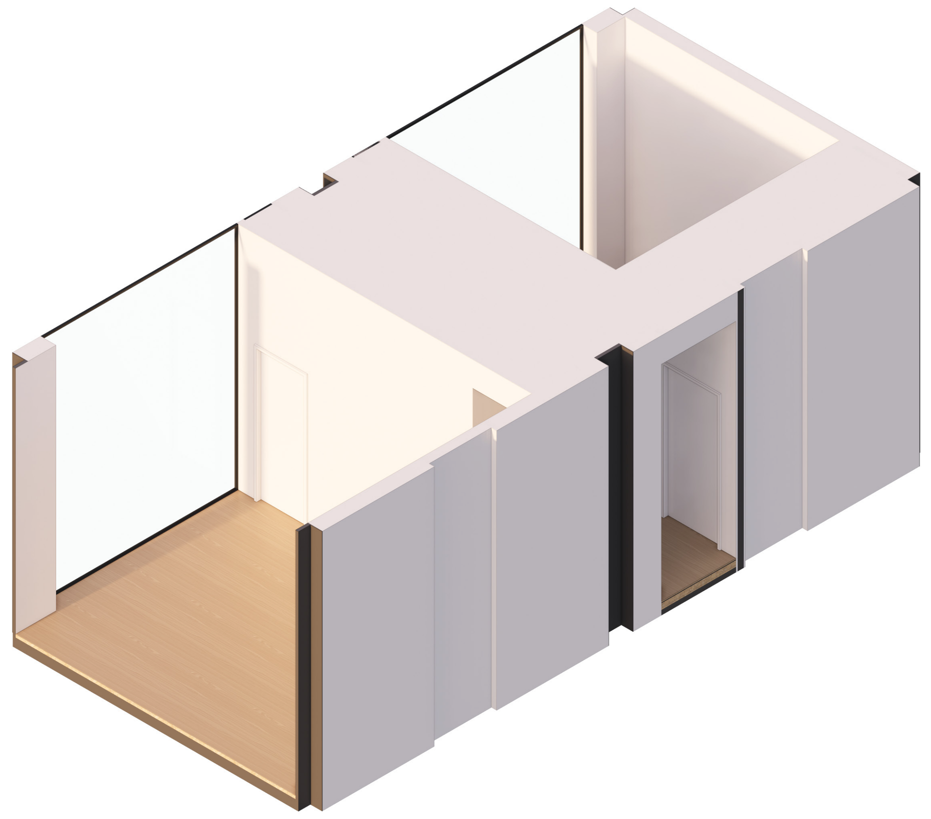
MODULAR OPTIONS

Module options vary depending on the buyers required features. Below are 4 standard module options which can be further customised. Bedrooms and living rooms are interchangable with or without doorways and all main area sizes are standardised to ensure each space is useable or easily adaptable.

Note, ceilings are not shown here as these are designed with the roof module added on top. All other modules in the building will come standard with ceilings (as shown with the Retail & Community Module).

BED & BATH MODULE

The Bed & Bath Modular design includes 1 x bedroom, 1 x large bathroom with bathtub, wall storage along the entire central hallway as well as a dedicated laundry with seperate WC for larger families.

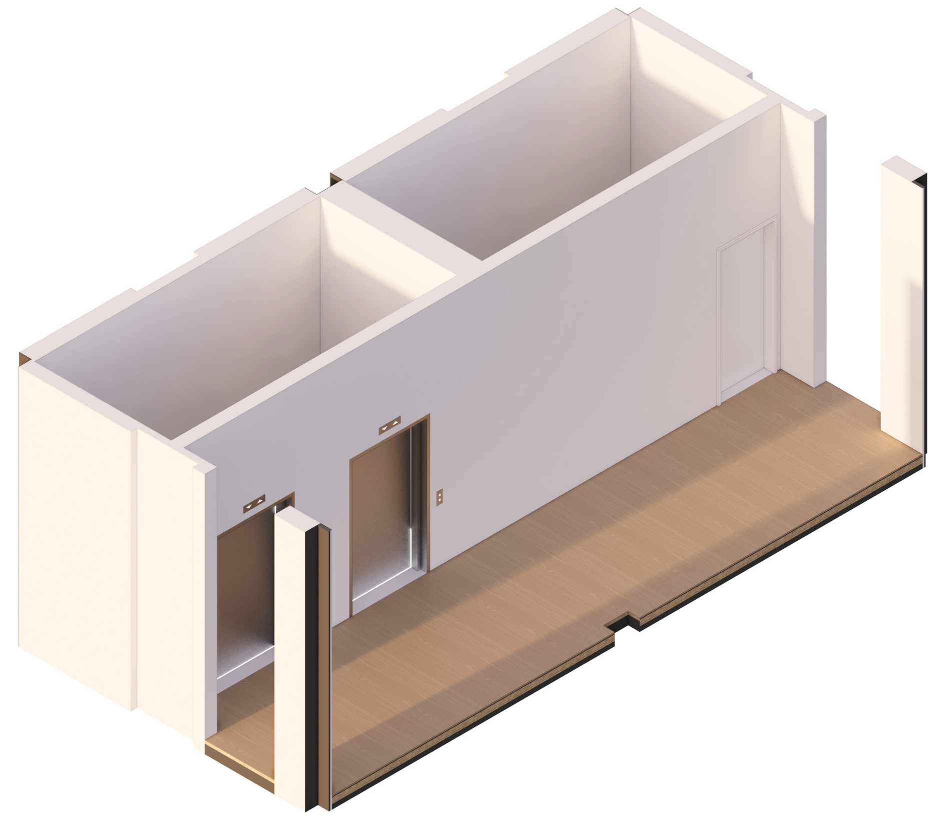


DUAL BED CORNER MODULE

The Dual Bed & Corner Modular design holds 2 x bedrooms and 1 x ensuite bathroom with 2 x seperated WC's for guests or those living in the apartment. This design caters more to those who want the guest bedroom/study with the main bedroom. This design is only allowed on the corners of the building.

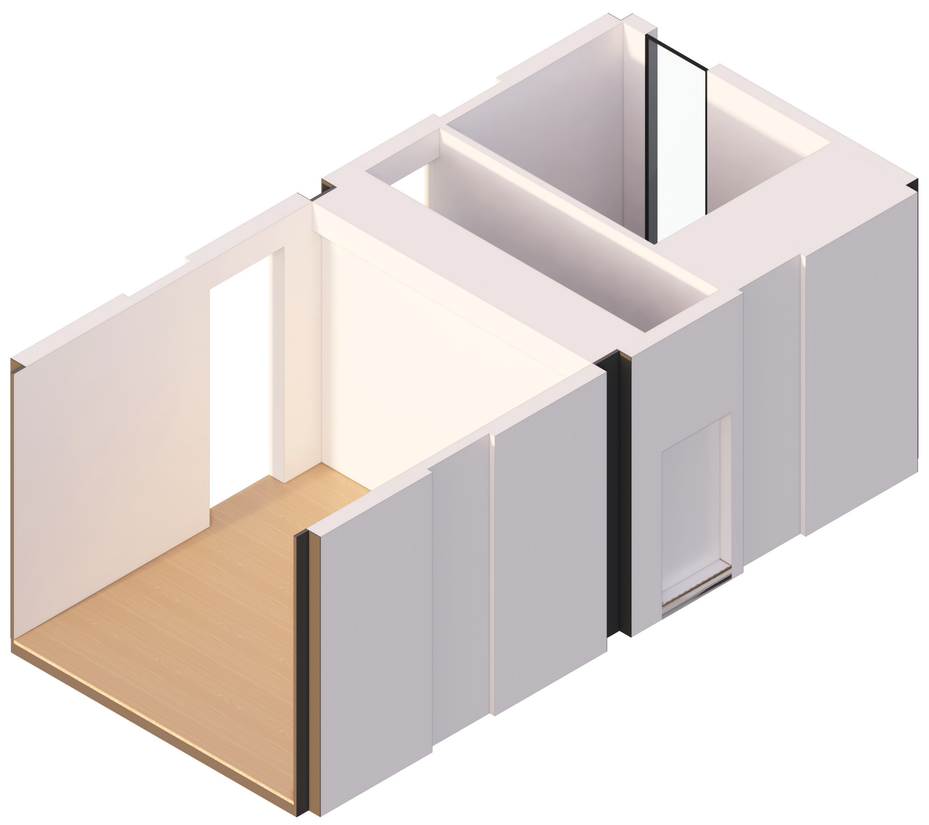
LIVING & KITCHEN MODULE

The Living & Kitchen Modular design is the most common available as it has been designed to hold a full sized kitchen, space for a 6 seater dining table (maximum) and a shared lounge room. For larger apartments, the lounge room can be used entirely as an oversized dining room, with the loungeroom in the living & study module. Creating a true entertaining experience.



LIFTS & FIRE STAIRS MODULE

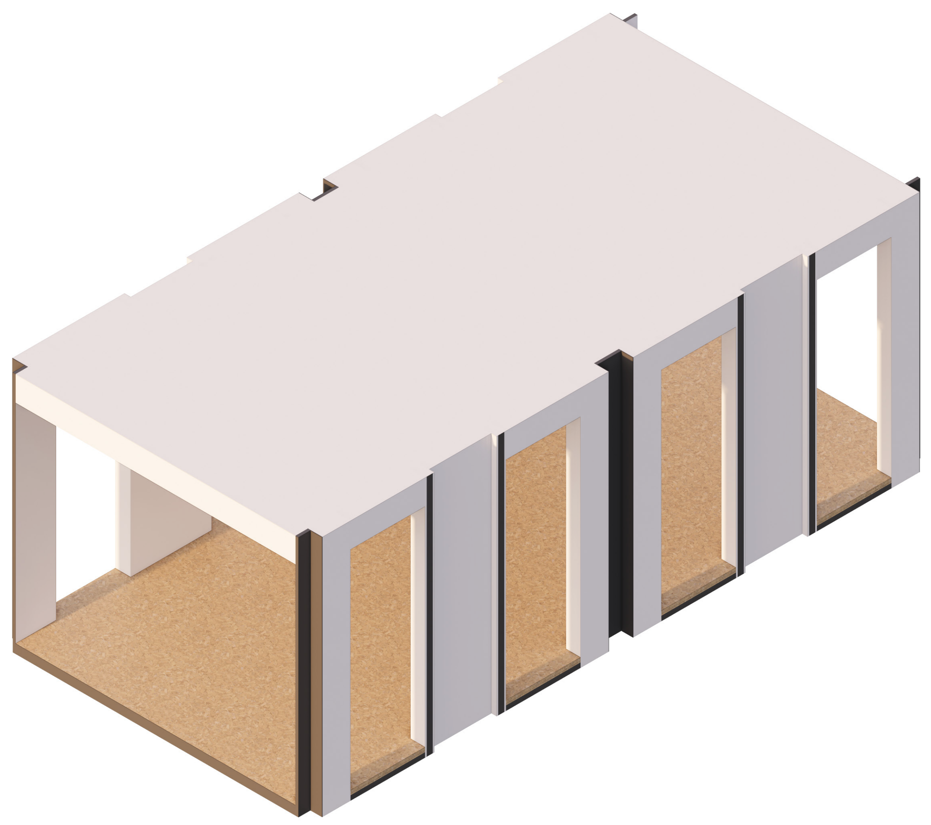
For each level increment the design goes up, a Lifts & Fire Stairs module is required. This houses 1 x large services lift and has the option for a second passenger lift for residents. A fire rated stair case is also housed in this module, to code with 1000mm width clearance for each stair run and connects to the floor below or above. These modules allow fire compliance without approval if the design is expanded in the future (up to 6 stories).



LIVING & STUDY MODULE

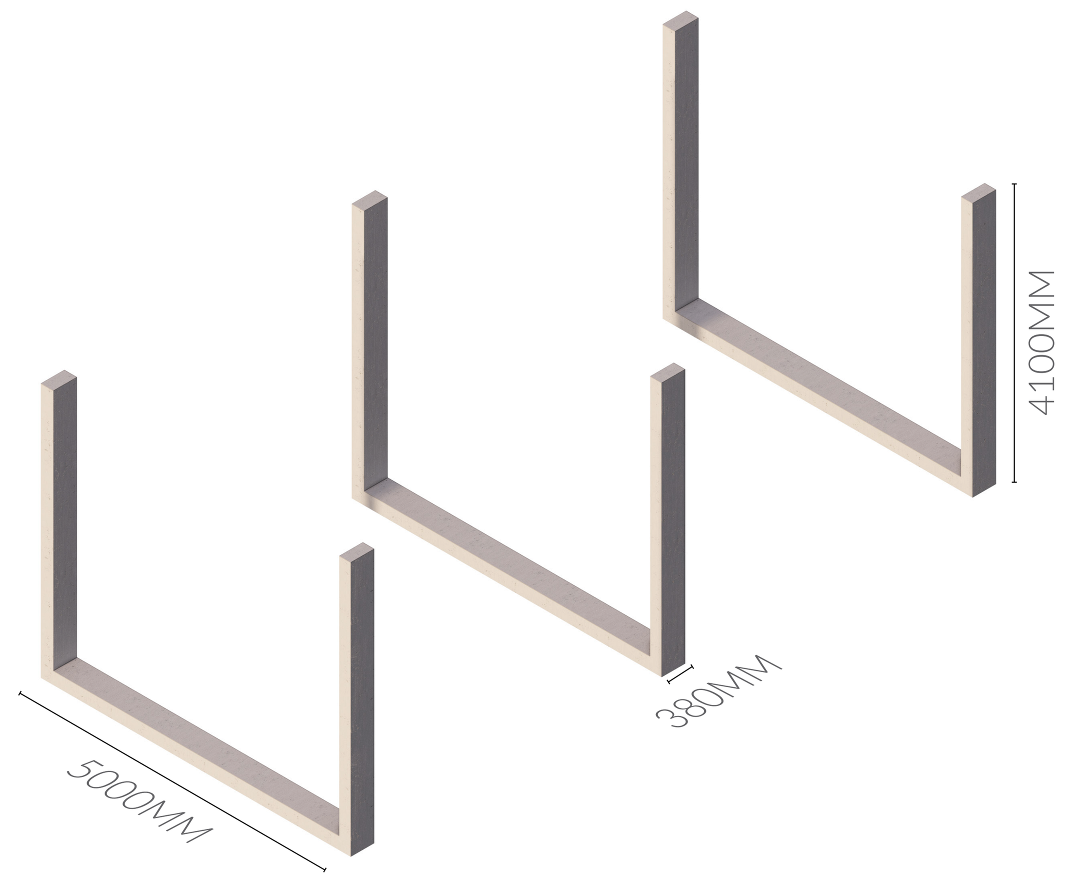
The Living & Study Modular design includes 1 x bedroom, 1 x study, wall storage along the entire central hallway as well as a dedicated store room that can hold larger items.

The Living and study module expands on the living elements of a home, with an aim of creating more space for growing families or those who required it.



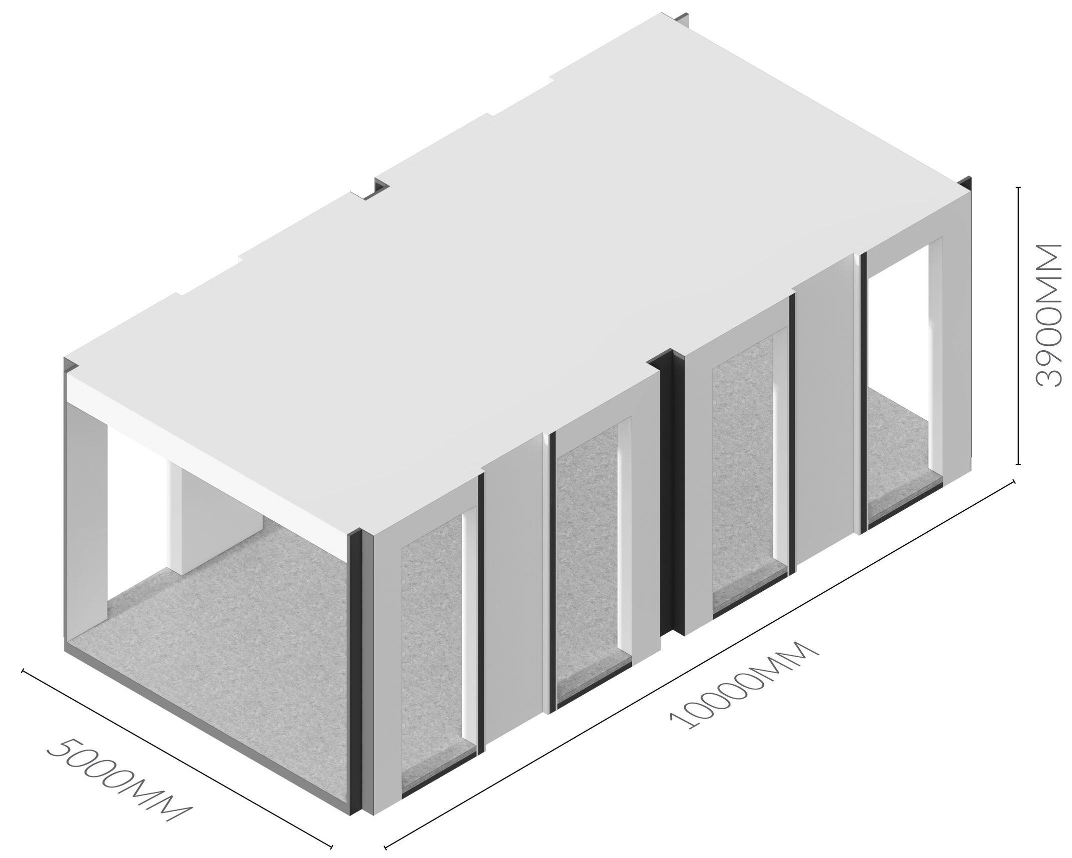
CUSTOM RETAIL & COMMUNITY MODULE

The Retail & Community Modular design is a standardised requirement with only the structure, chipboard sub-floor, walls and services attached. It is aimed for retail or community spaces that will be developed in the future or that require a blank canvas for customised infilL. This module can also be used by residents who require a custom fit out for a specific design



STEEL/CLT/CONCRETE SUPER STRUCTURE

The super structure is made up of a 5000 x 4100 x 380mm frame at 180mm thick to hold a Concrete, Steel, or Cross Laminated Timber framing typology. For the engineering drawings, steel was the primary consideration, however it is easily interchangeable with CLT. Concrete is available if materials are in short supply, however holds the highest embodied Co2 and is therefore not recommended.



MODULE DIMENSIONS

Every modular design follows the same dimensions strategy and does not deviate under any circumstrance. The sub-floor without a final surface finish such as timber or tiles is 150mm thick, and the ceilings are 400mm thick. With a total internal height of 3350mm (h). This ample height increases well-being for occupants and shifts away from low ceilign heights.

SERVICES

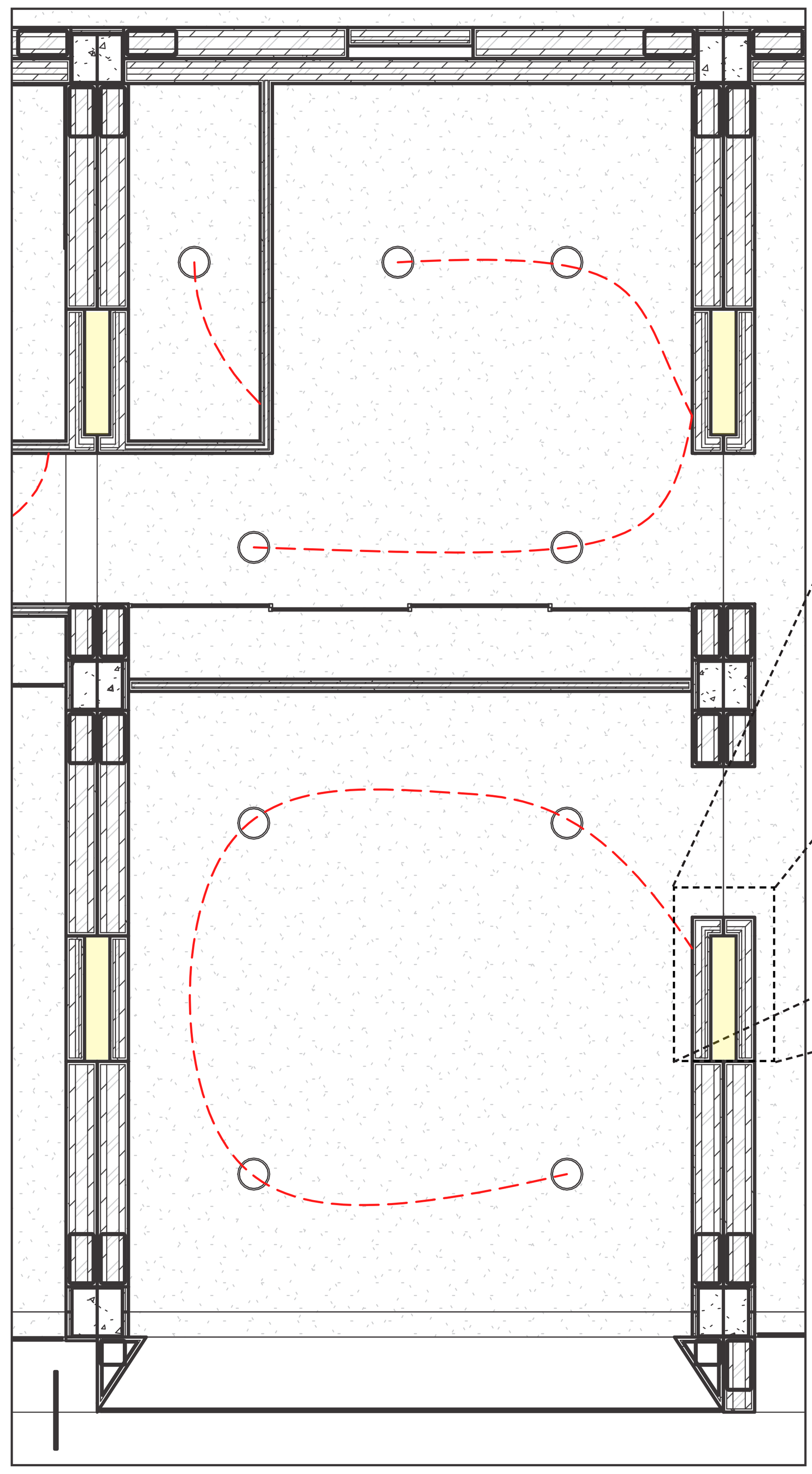
Modules utilise FOUR - 1000 x 100 x 4100 services ducts by arriving to site fitted with electricity, water, and waste piping already pre-installed. When the modules are placed side by side, the ducts double in width from 100mm wide to 200mm wide, hence being named 1000 x 200 ducts.

Each module is seperated vertically by the 200mm super structure framing, allowing services to connect to each other at these 4 points easily. If the framing system of the building pushes and pulls, all the services will still connect to the module below.

Water harvesting is easy with this design, as balcony & roof modules will have their rainwater funnel down the water harvesting pipe into the tank room for re-use.

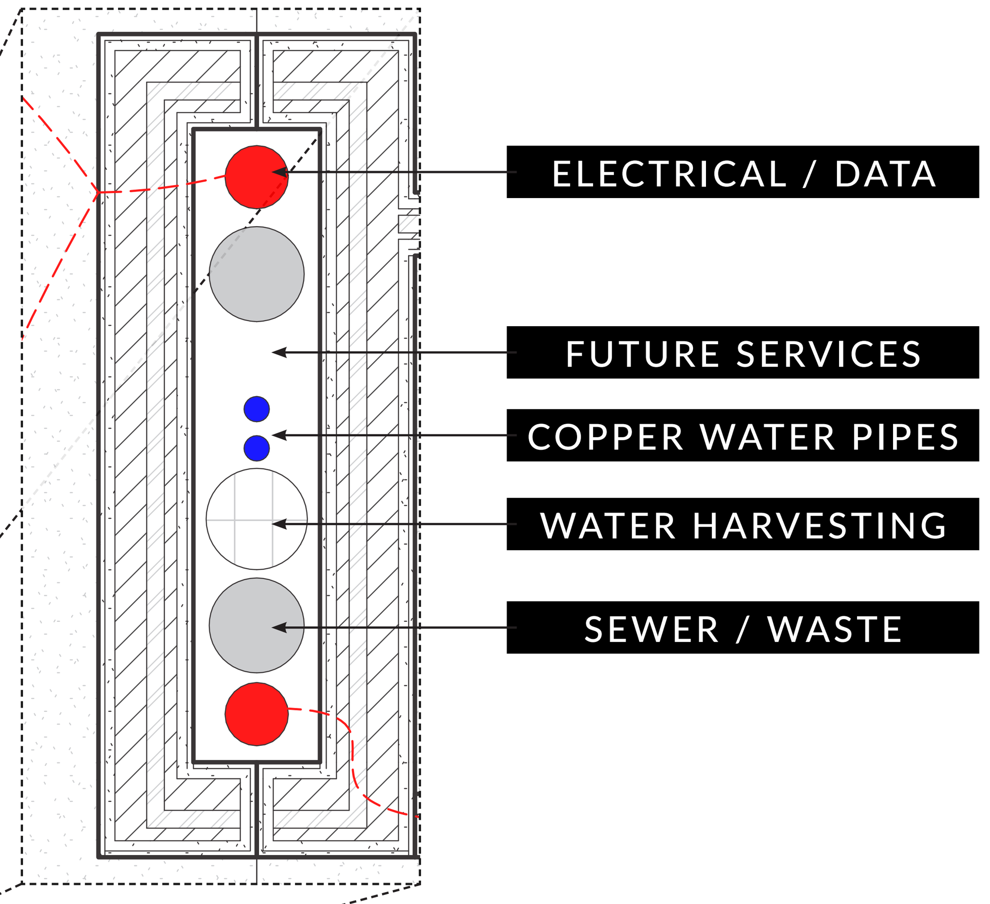
SERVICES KEY

- Water Duct
- Plumbing Connection
- Electrical Duct
- Electrical Wiring
- Electrical Lights
- Electrical Powerpoint
- Waste Plumbing
- Service Ducts



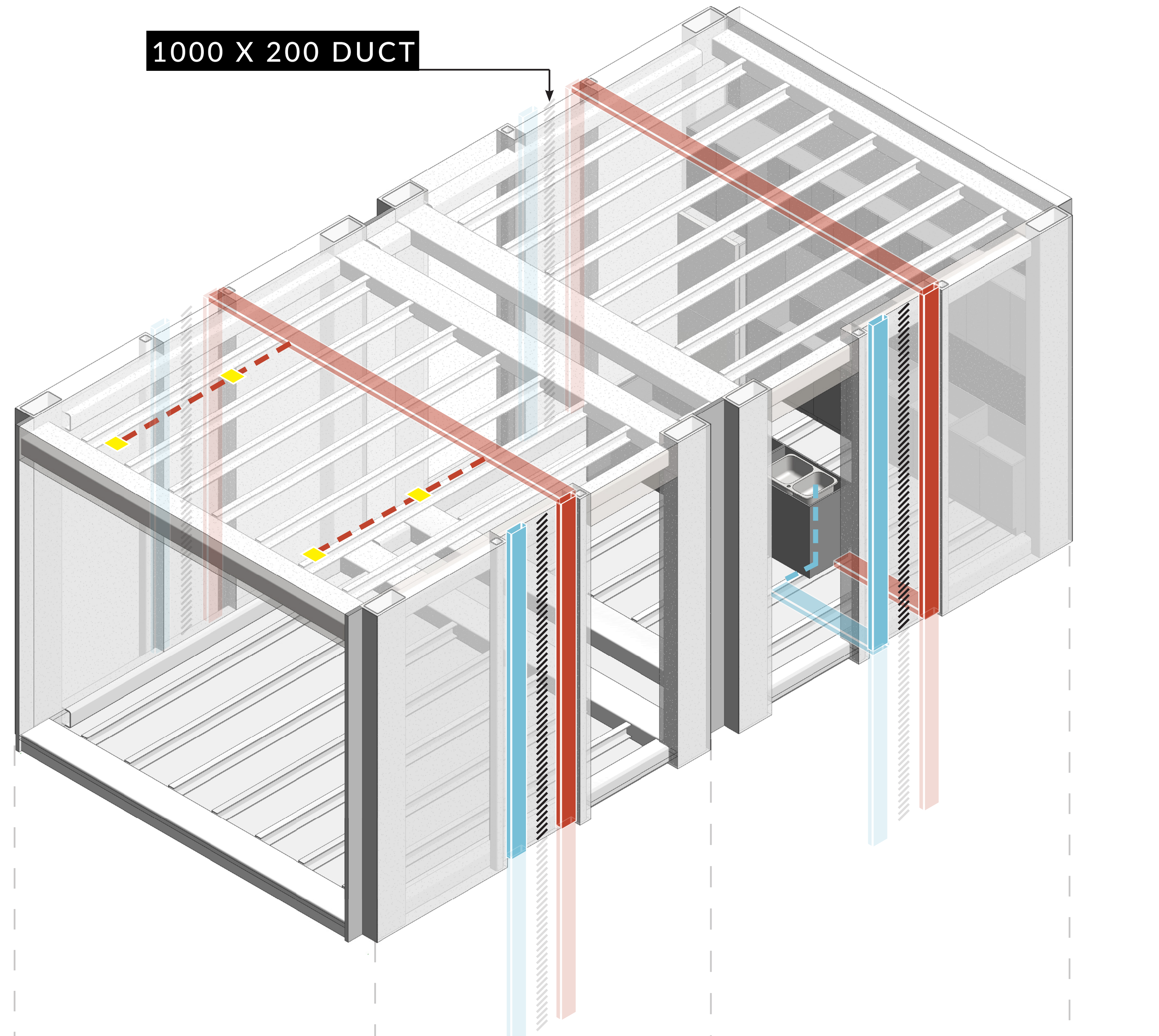
CEILING PLAN - ELEC + SERVICES

SCALE 1:50

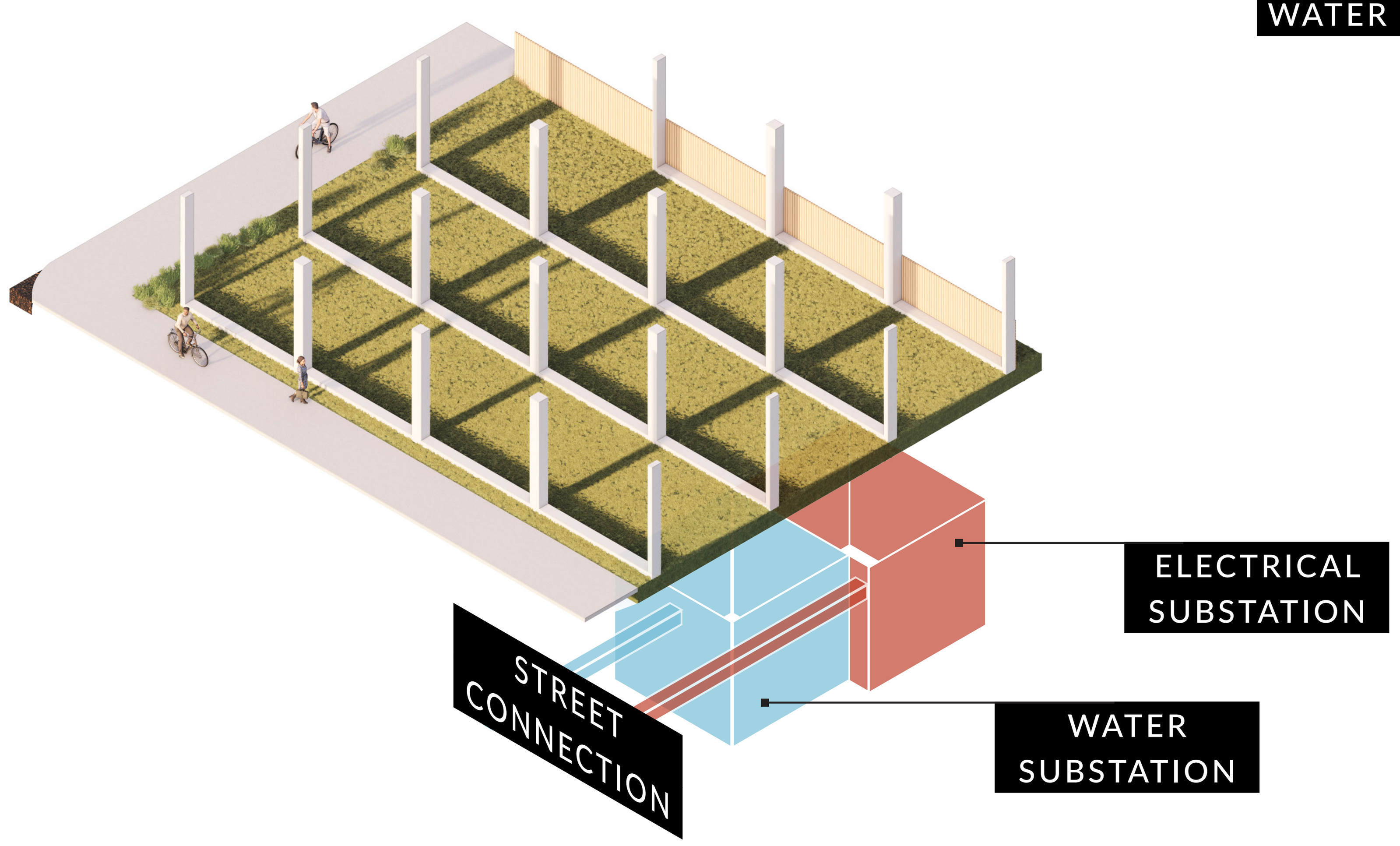


SERVICE DUCT

SCALE 1:10

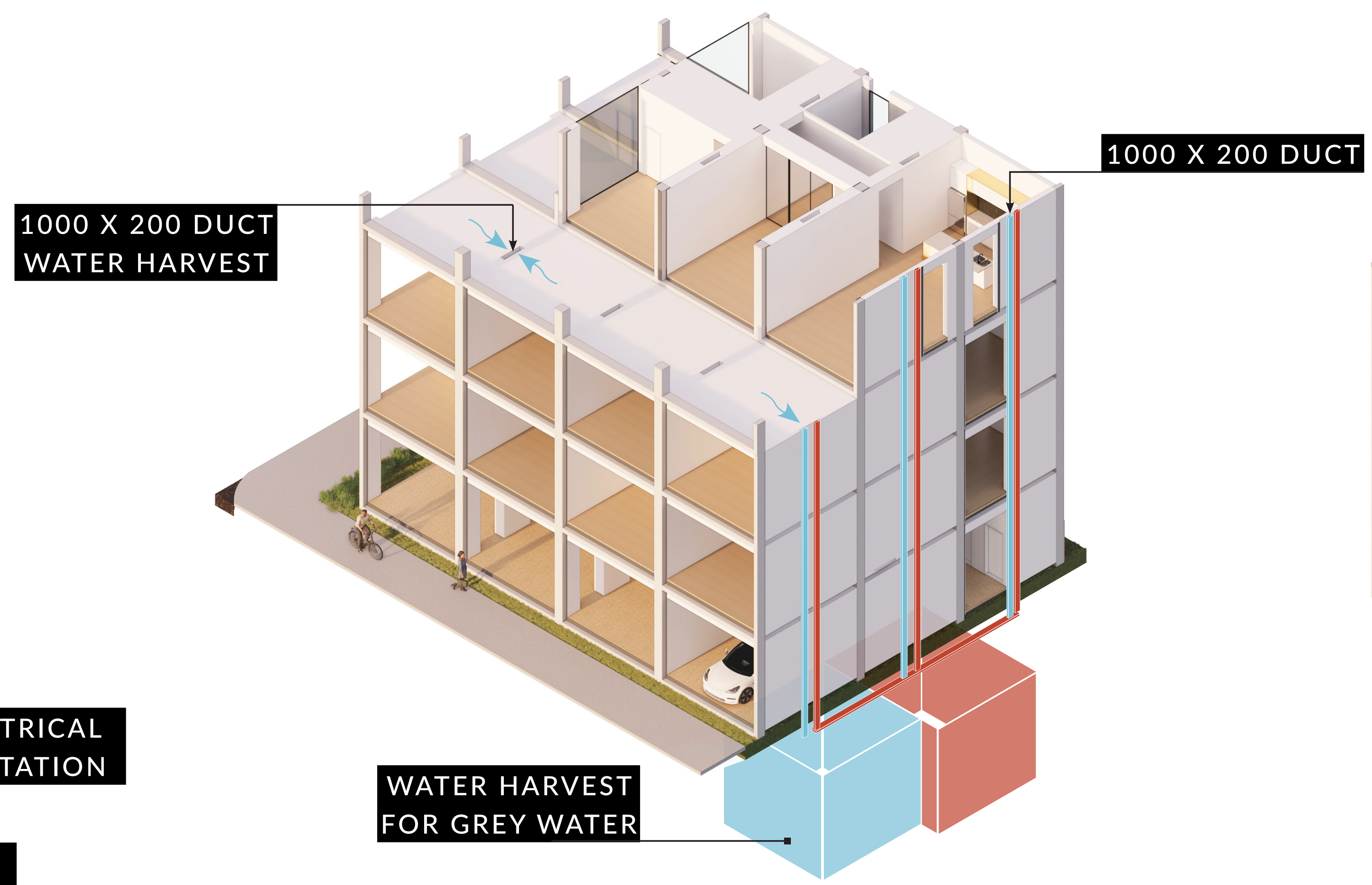


MODULAR SERVICES (EXOSKELETON)



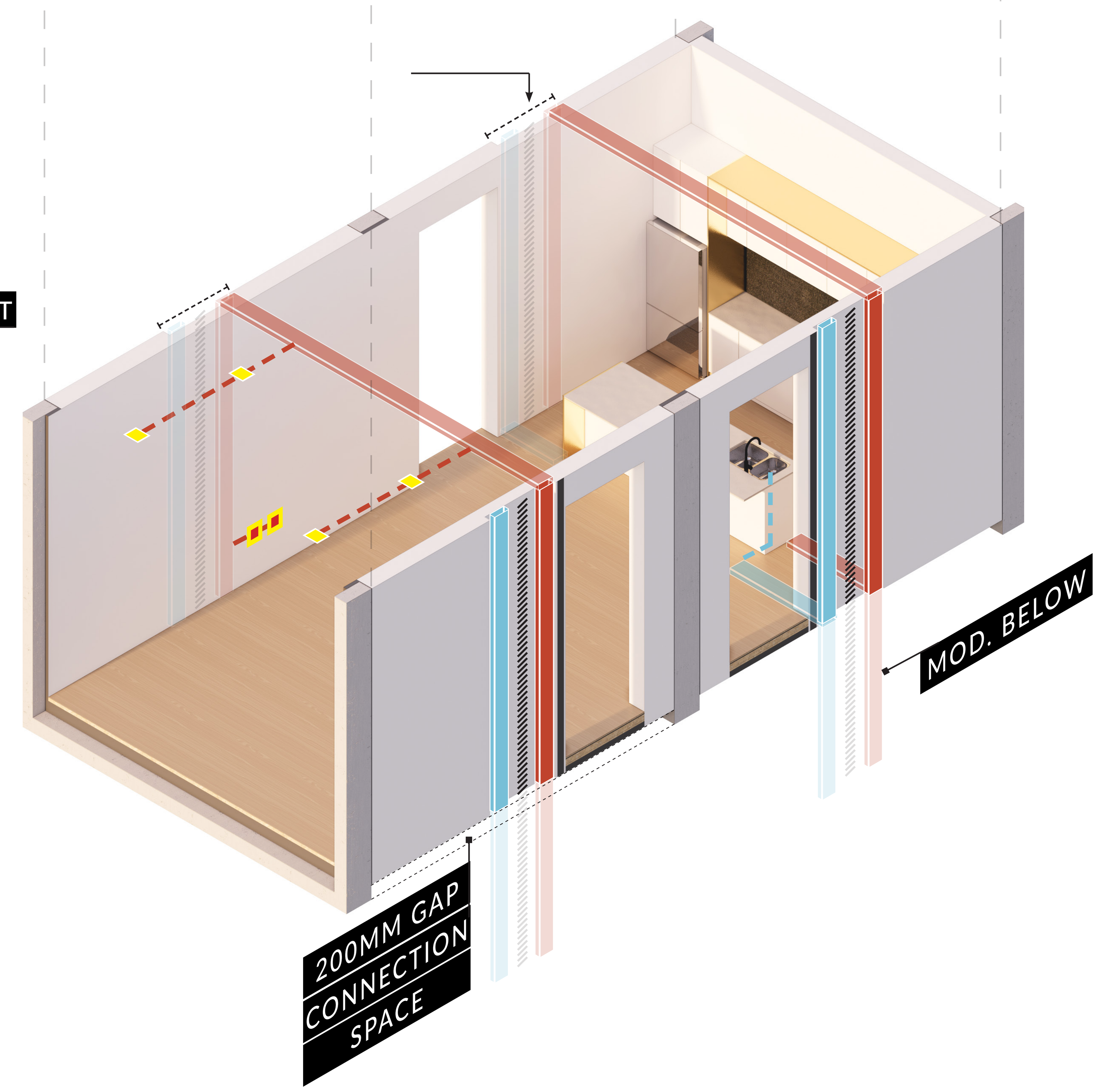
UNDERGROUND SUBSTATIONS

Substations below ground connect to the street and hold all water storage tanks from roof water harvesting and all pump rooms. The Electrical substation houses battery storage for solar power, all mechanical services and fibre optic internet connections. Accessed through the emergency fire stairs, the substations are designed to service all vertical services connections in the building.



SET BACK CODE + VERTICAL SERVICES

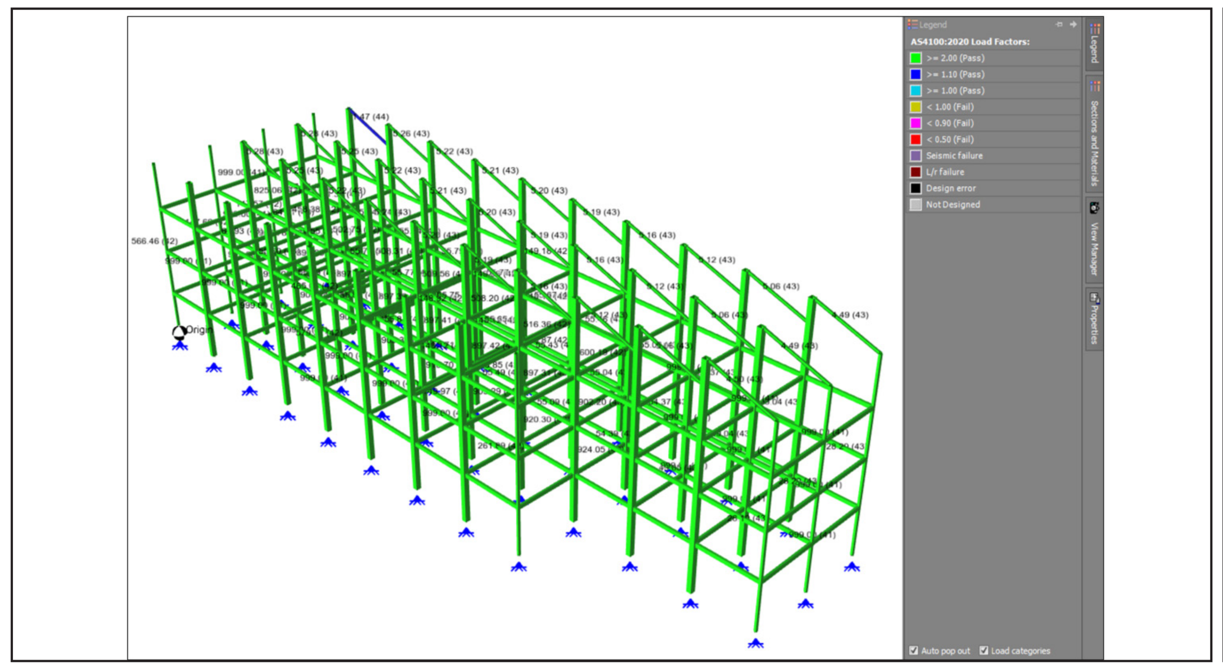
Modules can be set back in the frame to abide council set back codes by 5 metres at each increment. Allowing unique designs to form on awkward lots and reduce over-shadowing. Modules can still connect to the vertical services due to the 4 key service ducts that allow connections for each module. If any service point is not functional, they can be re-directed to one of the other 3 available.



MODULAR SERVICES (RENDERED)

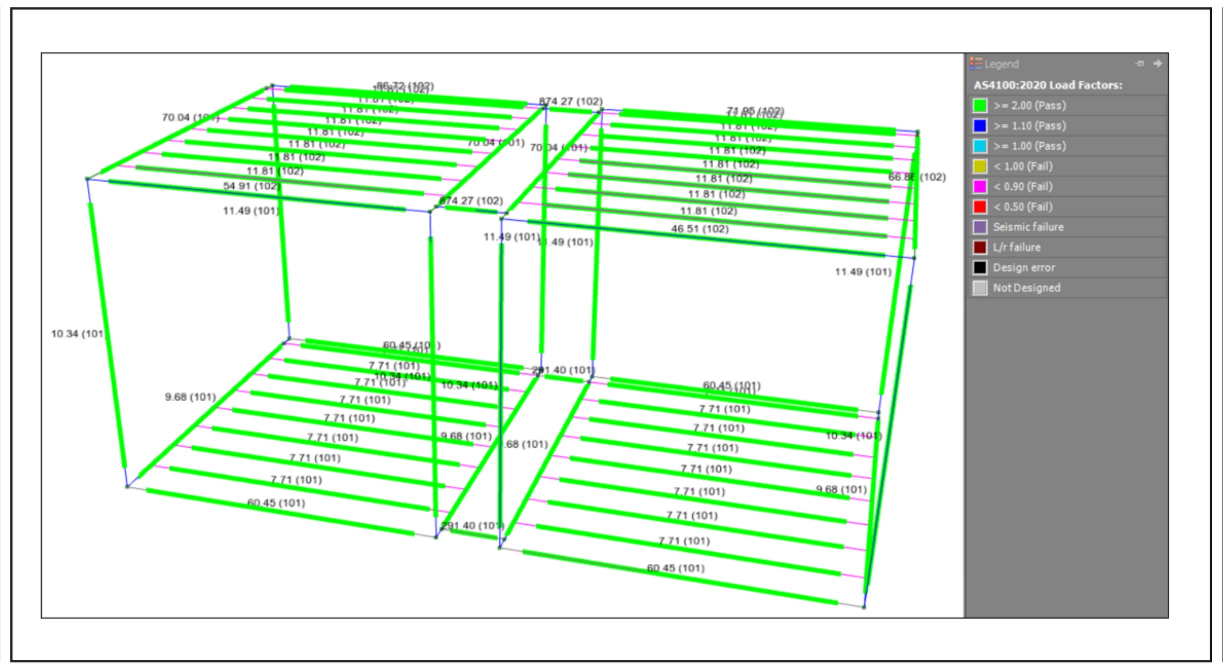
The centralised location of these services makes major renovations of the modules easier in the future. Easy connection to services points within the structure allows kitchens or bathrooms to be moved to other locations at the 50 year cycles. This encourages continued use of existing modules and as much embodied materials as possible. Reducing waste and energy/water intensive recycling processes.

ENGINEERING REPORT - SUMMARY



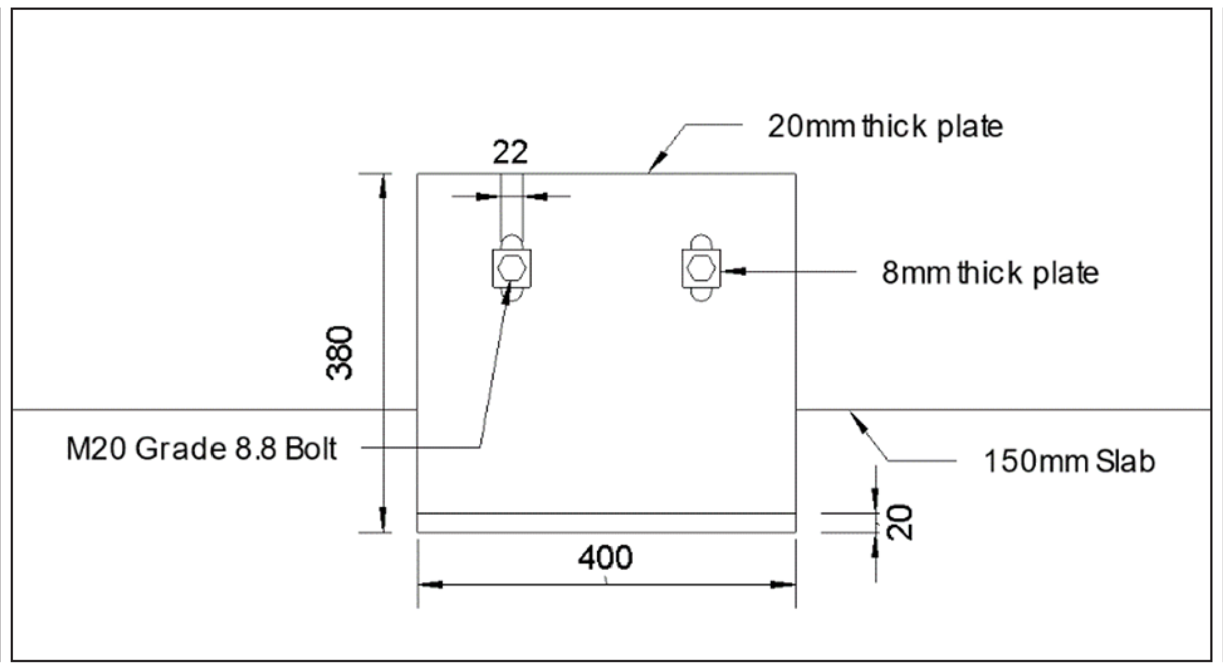
SUPER STRUCTURE CRITICAL LOAD

Based on SpaceGass analysis, all super structure members can withstand the critical load combination acting on the structure. The deflection, shear force, and bending moment acting on the super structure due to the load combination is shown above. The superstructure was deliberately seperated from the modules to ensure easy future replacement without total loss of modules and achieve 100 year life cycle.



CRITICAL LOAD COMBINATION

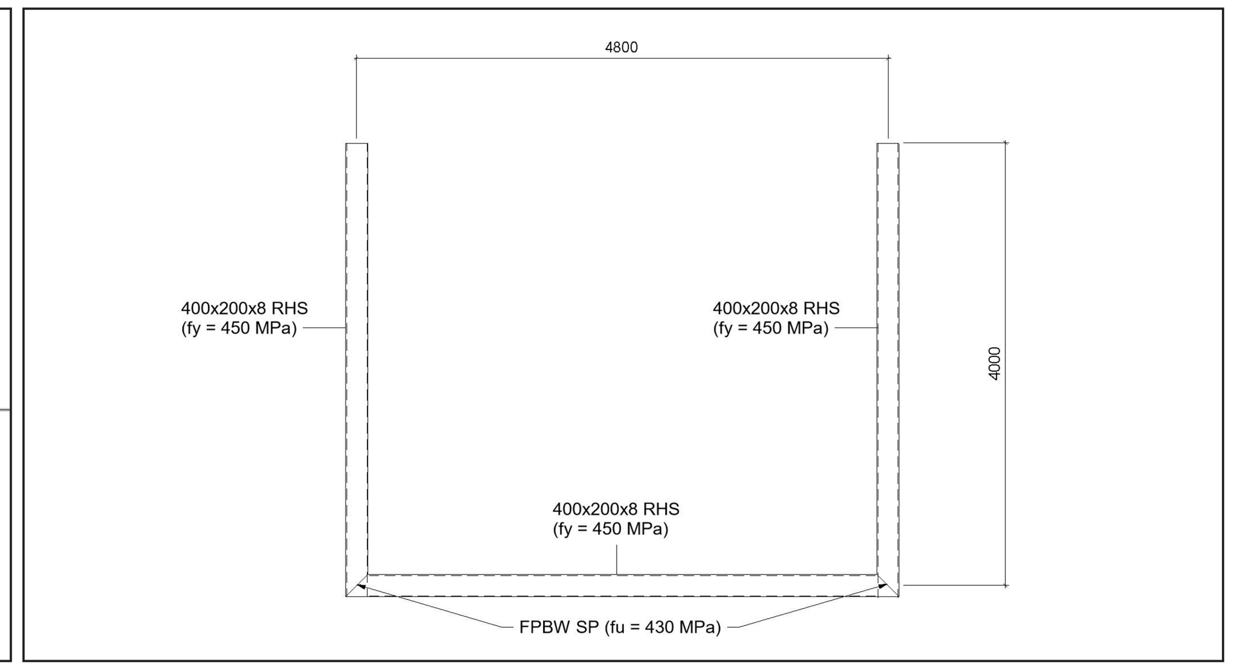
Based on SpaceGass analysis, all members can withstand the critical load combination acting on the structure. The deflection, shear force, and bending moment acting on module 1 due to the load combination is shown above. The modules feature their own structural intergrity seperated from the super structure for easy renovations or future transfer of ownership. Aimed at achieving the 100 year life cycle for embodied energy.



FACADE CONNECTION

The simple facade connection utilises a 20mm thick steel plate with an 8mm thick steel plate washer with a M20 Grade 8.8 bolt to secure the facade to the concrete super structure.

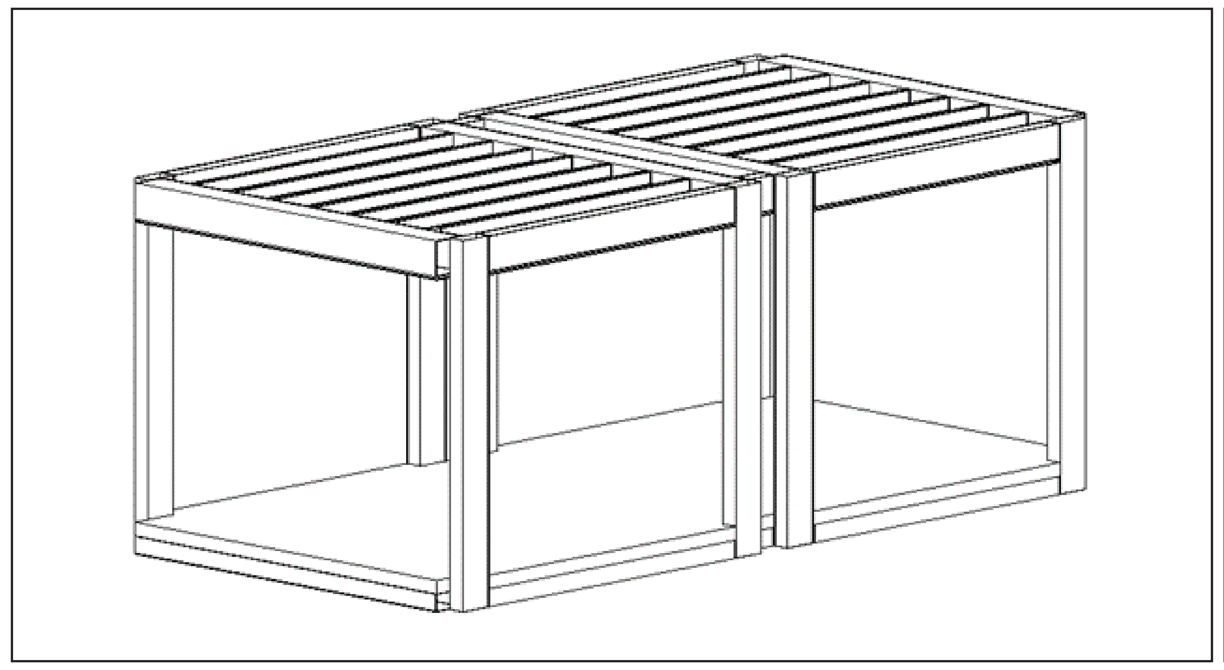
Load transfer also occurs against the 150mm concrete slab and the 400 x 200 x 8 RHS Steel Beams (fy = 450MPa) (Concrete & CLT alternatives can also be used for the beams)



CONCRETE SUPERSTRUCTURE U-SHAPE

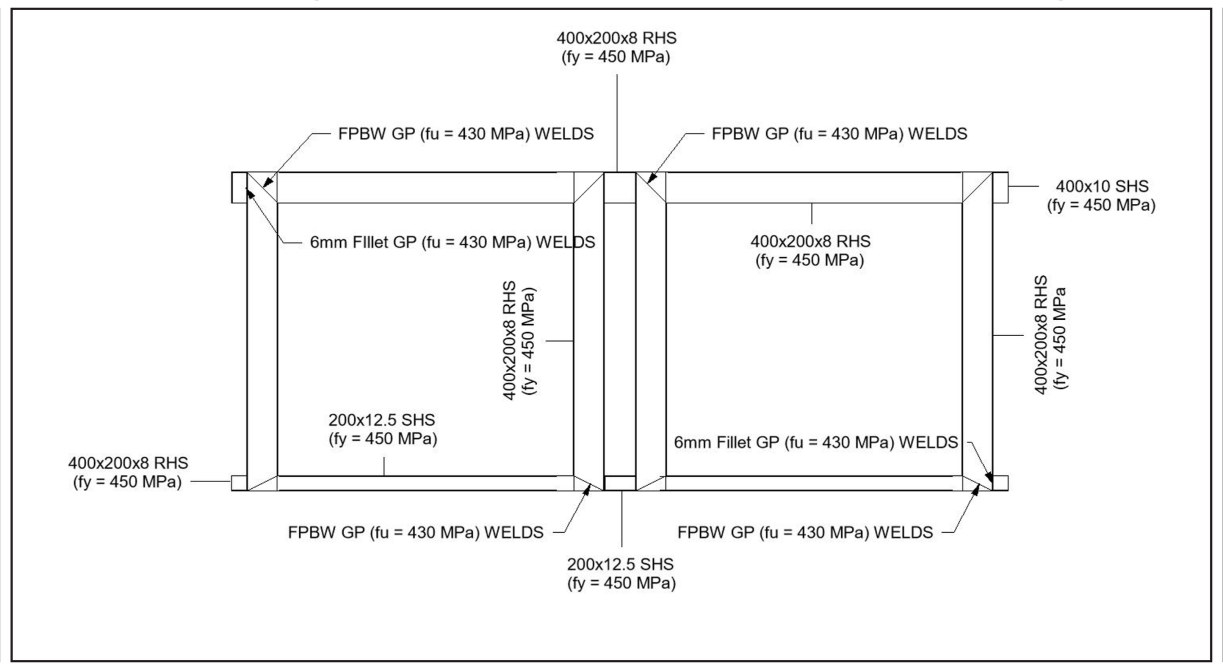
The superstructure utilises a simple prefabricated U-Shape steel beam that consists of 3 x 400 x 200 x 8 RHS (fy = 450 MPa).

Alternatively, these design dimensions also allow CLT Timber & prefabricated formed concrete options to create the super structure. This allows the design to adjust and change depending on materials available or embodied energy requirements.



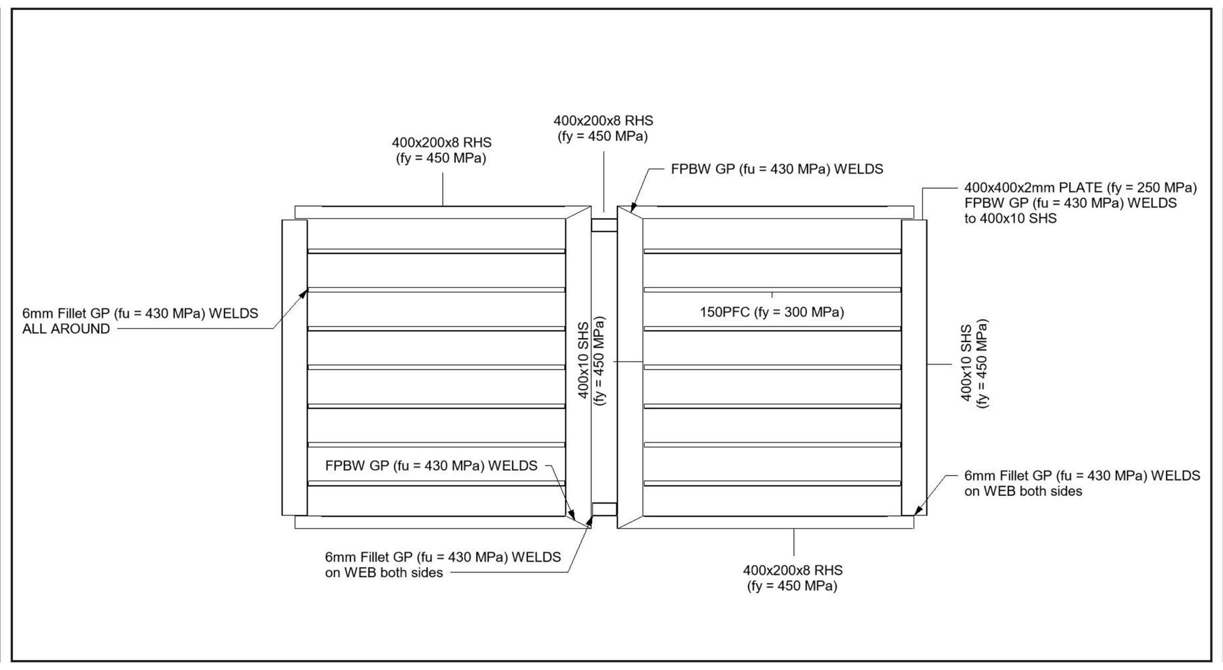
MODULAR STRUCTURE 3D

The materials used to construct the prefabricated modular house are steel. Unlike timber, steel materials does not need to be treated for termite or decay. Steel frames are lighter, more durable, long lasting and cost effective to assemble. They also resist forces of bending and flexing. Steel structures can last for many decades when maintained properly.



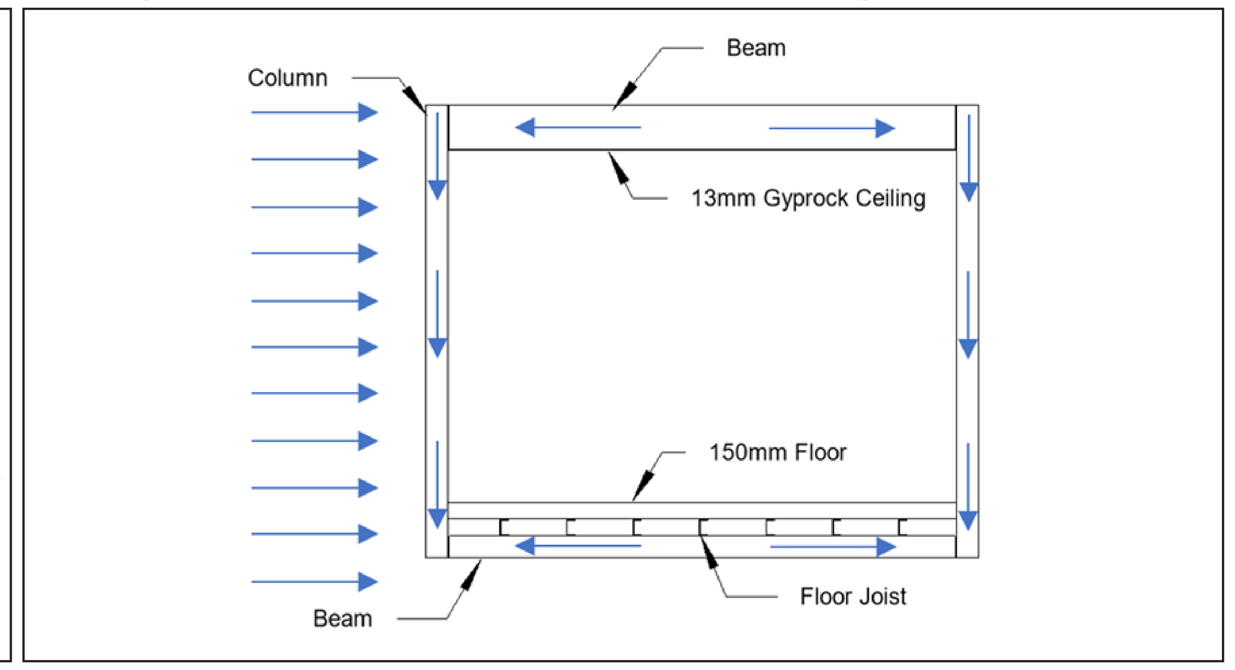
MODULAR STRUCTURE ELEVATION

The steel prefabricated modular structure creates structural integrity through the above arrangement of steel members. Alternatively, CLT can be used instead to reduce embodied carbon in the future as technology advances. Ensuring the design is adaptable for future construction methods.



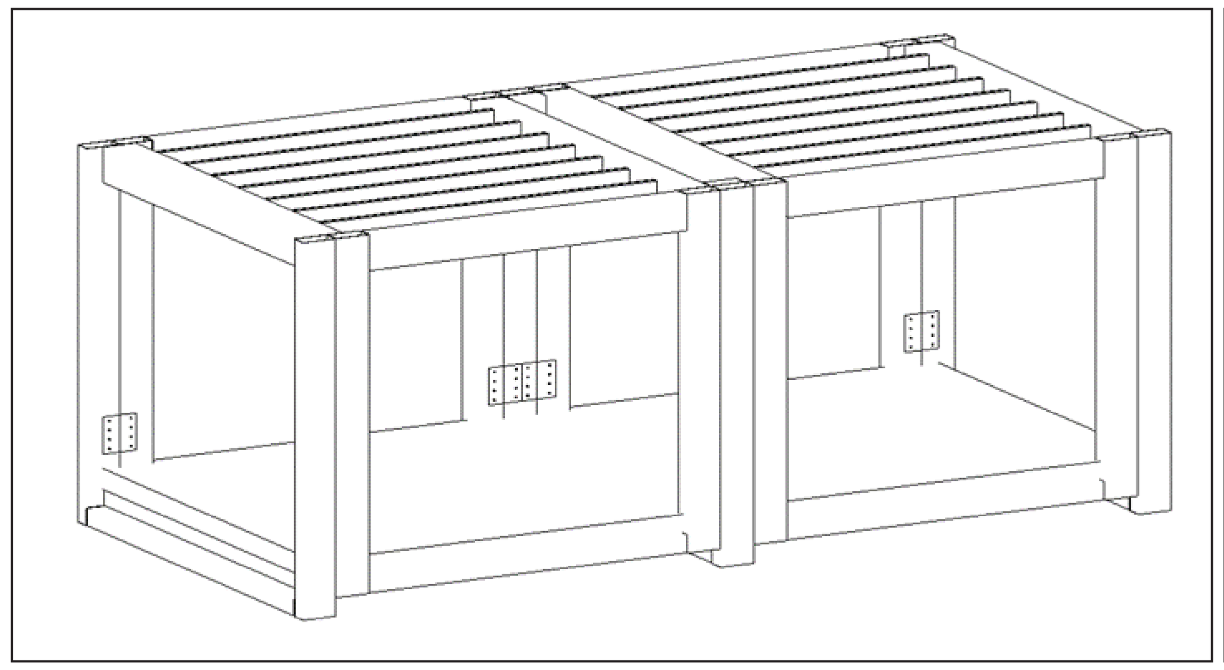
MODULAR STRUCTURE PLAN

The plan view demonstrates the minor cross-members for ceiling and floor framing. Floor framing can be changed out for a 150mm concrete slab, reinforced steel structure or CLT structure as technology advances. The structural design dimensions of 400 x 200 x 8mm RHS allow substantial structure adjustments using different materials without impacting the overall design intentions or connection to older apartments.



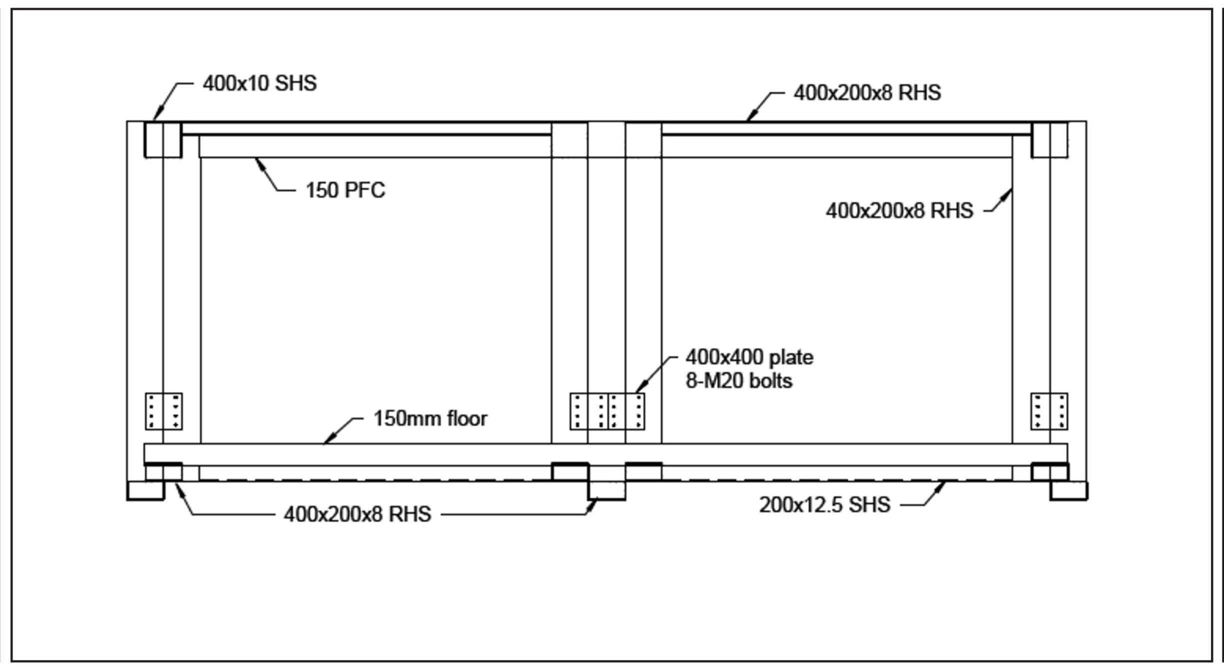
MODULAR LOAD TRANSFER SECTION CUT

Structural Materials:
Lysaght Zeds - Purlin
Universal Beam - Rafter
Lysaght TRIMDEK - Roof Cladding
Parallel Flange Channel (PFC) - Floor Joists
Square Hollow Section (SHS) - Floor Beam
Rectangular Hollow Section (RHS) - Columns, Floor/Roof Beams



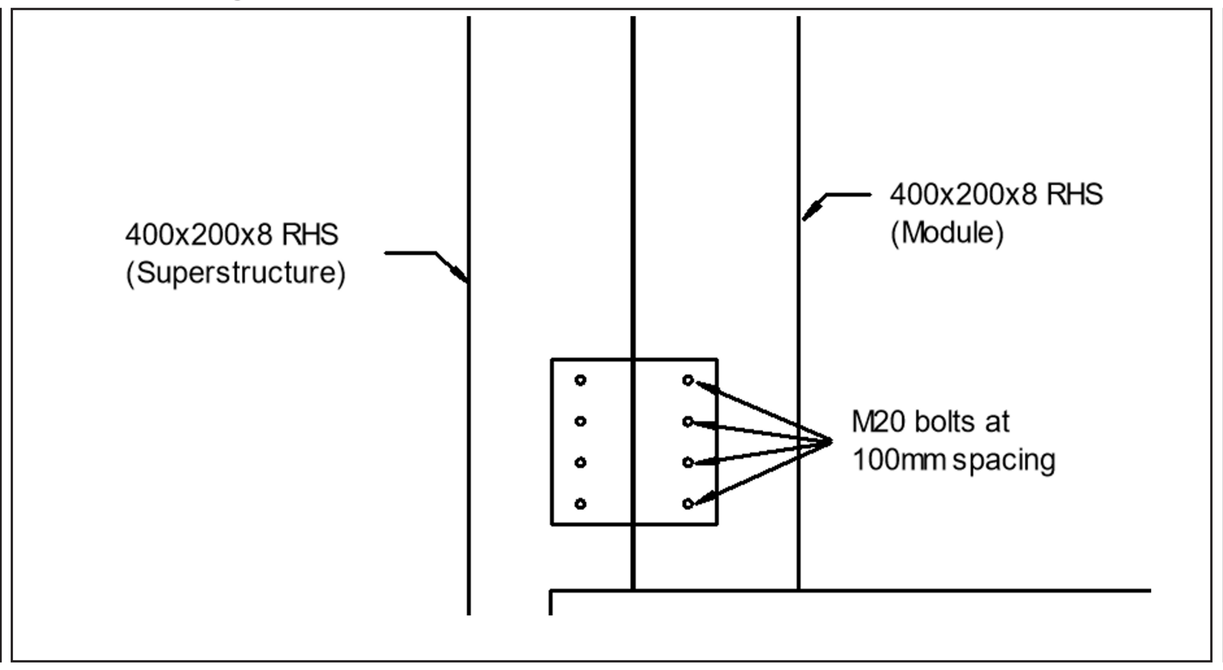
MODULAR CONNECTION 3D

Modular construction material chosen:
Parallel Flange Channel (PFC) - Floor/Ceiling Joists
Square Hollow Section (SHS) - Floor Beam
Rectangular Hollow Section (RHS) - Floor/Ceiling Beam



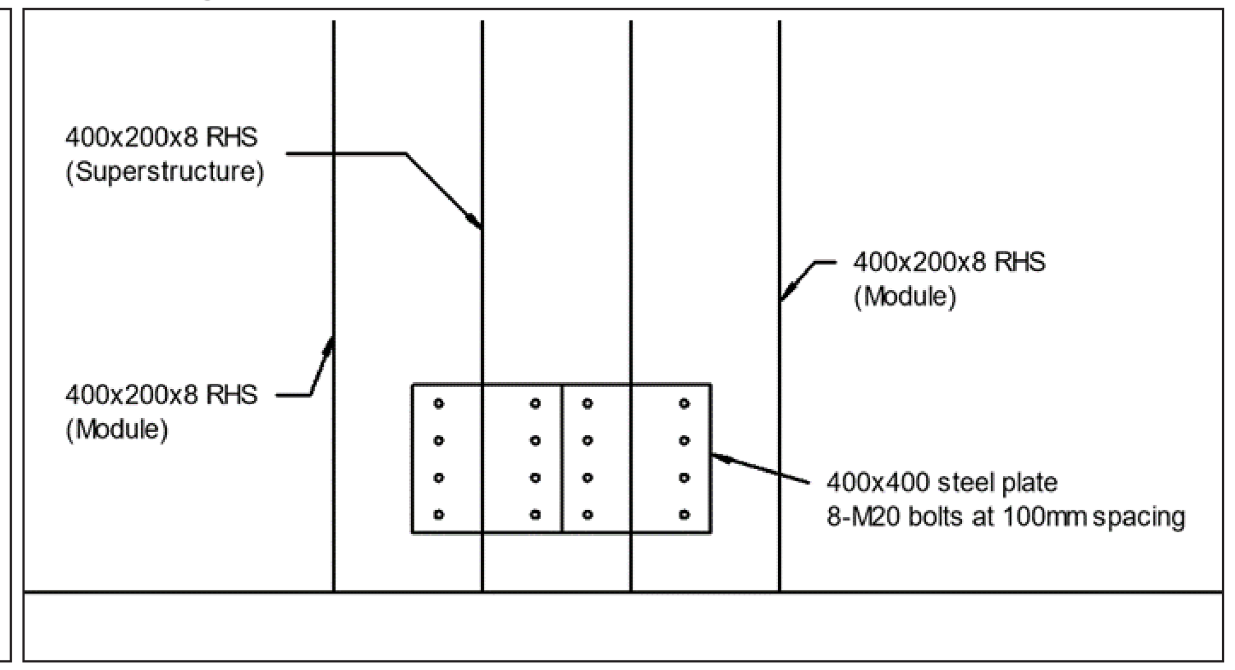
MODULAR CONNECTION ELEVATION

400 x 400 x 8mm Plates secure the modules to the superstructure. Plates are wrapped in 47mm Gyprock, Fire Check and Chipboard panels to ensure fire safety has been achived. 8mm M20 bolts secure the plates to the Steel/CLT modular structure with the Steel/CLT/Concrete Super Structure. Locking the units.



MODULAR CONNECTION ELEVATION

Each corner of the modular design connects to the super structure using the same 400 x 400mm plate with 8mm M20 - Bolts.



MODULAR CONNECTION ELEVATION

For centre connections and facade connections, the modular design connects to the super structure using the same 400 x 400mm plate with 8mm M20 - Bolts. For facade connections, this additional plate ensures that cantilivers of 10 and 20% the total distance of the module is supported and distrubuted.

SECTION CUT

REFERENCES

Yu, Man., Wiedmann, T., Crawford, R. Tait, C. 2017. The Carbon Footprint of Australia's Construction Sector. Procedia Engineering.
https://doi.org/10.1016/j.proeng.2017.04.180. (https://www.sciencedirect.com/science/article/pii/S1877705817316879)

SCALE 1:100

1.1. Module 1

Table 1: Module 1 - Structural Members

Structural Elements	Materials	Specification
Ceiling	Gyprock	Thickness: 13 mm Weight: 8.5 kg/m^2
Ceiling Joists	150PFC	Depth: 150 mm Width: 75 mm Weight: 17.7 kg/m
Ceiling Beam	400 x 10 SHS	Width: 400 mm Depth: 400 mm Thickness: 10 mm Mass per m: 120 kg/m
Floor	Hebel PowerFloor	Thickness: 150 mm Density: 580 kg/m^3
Floor Joists	150PFC	Depth: 150 mm Width: 75 mm Weight: 17.7 kg/m
Floor Beam (short span)	400 x 200 x 8 RHS	Width: 400 mm Depth: 200 mm Thickness: 8 mm Mass per m: 71.6 kg/m
Floor Beam (long span)	200 x 12.5 SHS	Width: 200 mm Depth: 200 mm Thickness: 12.5 mm Mass per m: 69.4 kg/m
Column	400 x 200 x 8 RHS	Width: 200 mm Depth: 200 mm Thickness: 12.5 mm Mass per m: 71.6 kg/m
Wall	Gyprock	Thickness: 13 mm Weight: 8.5 kg/m^2

1.2. Lifting of Module

The type of sling to be used in lifting the module is a chain sling. Chain slings grades can be manufactured with 80 up to 100-grade chains. They come with a wide range of length, capacity and hooks (latch and safety hooks). They are also designed to withstand the different conditions consisting of sites, factories, warehouses, etc. (Ryan 2019). They come in different numbers of legs including single, two and four-legged slings. The workload limit (WLL) can go up to 67 tonnes (Ryan 2019).

The lifting chain that will be used in the placement of modules are in accordance with AS3775.1 (2014) Appendix D <Table D2> shown in Figure 1. The chain size selected is a 16mm chain and its working load limit is up to 10 tonnes.

1	2	3	4	5	6	7
Chain size	Single-leg master link and components			Master and intermediate links (2, 3 and 4 legs)		
	WLL	Proof force	Breaking force	WLL (see Note 3)	Proof force	Breaking force
mm	t	kN	kN	t	kN	kN
4	0.63	12.4	24.7	1.1	21.6	43.2
5	1.0	19.6	39.2	1.7	33.4	66.7
6	1.4	27.5	54.9	2.4	47.1	94.2
7	1.9	37.3	74.6	3.3	64.7	129
8	2.5	49.1	98.1	4.3	84.4	169
10	4.0	78.5	157	6.9	135	271
13	6.7	131	263	11.6	228	455
16	10	196	392	17.3	339	679

Figure 1: Sling Working Load Limits GradeV[100]

The safe working load is calculated below:

SWL = (L)(WLL)

= 1.73 x 10

= 17.3 tonnes per 1 leg

Lifting the module require 4 legs:

= 17.3 x 4

= 69.2 tonnes

2. Design Actions

2.1. Permanent Loads

The permanent load of the members is shown in the table below, detailed calculation is shown in Appendix A.

Table 2: Member Loads

Module	Member	Weight	UDL (kN/m)
1	Ceiling	8.5 kg/m^2	0.42
1	Ceiling joist	17.7 kg/m	0.17
1	Ceiling beam (short span)	120 kg/m	1.18
1	Ceiling beam (long span)	71.6 kg/m	0.7
2	Roof sheeting	4.35 kg/m^2	0.047
2	Roof purlin	2.62 kg/m	0.026
2	Roof rafter	25.4 kg/m	0.25
2	Roof beam	71.6 kg/m	0.7
1, 2	Floor	580 kg/m^3	2.13
1, 2	Floor joist	17.7 kg/m	0.17
1, 2	Floor beam (short span)	71.6 kg/m	0.7
1.2	Floor beam (long span)	69.4 kg/m	0.68
1, 2	Column	71.6 kg/m	0.7
1, 2	Wall	8.5 kg/m^2	0.34

2.2. Imposed Loads

The imposed actions calculated on the tables below are for the roof and floor and are in accordance with AS1170.1. The detailed calculations are shown in Appendix B.

2.2.1. Roof

Table 3: Roof Imposed Loads

Type	Specific Uses	Uniformly Distributed Actions (kPa)	UDL (KN/m)	Concentrated Load (kN)	Reference
R2 Other Roofs	Structural Elements	0.25	1.25	1.1	AS 1170.1 <Table 3.2>

2.2.1.1. Rafter

Table 4: Rafter Imposed Loads

Type	Specific Uses	Uniformly Distributed Actions (kPa)	UDL (KN/m)	Concentrated Load (kN)	Reference
Rafter	Structural Elements	0.25	1.25	-	AS 1170.1 <Table 3.2>

2.2.2. Floor

Table 5: Floor Imposed Loads

Type	Specific Uses	Uniformly Distributed Actions (kPa)	UDL (KN/m)	Concentrated Load (kN)	Reference
A1 – Self-contained dwellings	General areas, private kitchens and laundries in self	1.5	7.5	1.8	AS 1170.1 <Table 3.1>

2.2.2.1. Floor Joists

Table 6: Floor Joists Imposed Loads

Type	Specific Uses	Uniformly Distributed Actions (kPa)	UDL (KN/m)	Concentrated Load (kN)	Reference
Floor Joists	General areas, private kitchens and laundries in self	1.5	0.75	-	AS 1170.1 <Table 3.1>

2.3. Wind Loads

2.3.1. Design Wind Speed

Table 7: Design Wind Speed

$V_{site}, \beta = V_R M_d (M_{z,cat} M_s M_t)$		**References**
Importance Level	2	AS 1170.0 <Table 3.1>
Design Life	50	Assignment Brief
Annual Probability of Exceedance (Ultimate)	1/500	AS 1170.0 <Table 3.3>
Annual Probability of Exceedance (Serviceability)	1/25	AS 1170.0 <Table 3.3>
47 Victoria Street, Midland WA (Perth)	Region A1 (non-cyclonic)	AS 1170.2 <Figure 3.1(A)>
Terrain Category	TC 3	AS 1170.2 Clause 4.2.1
Regional Wind Speeds		
V_R (Ultimate Wind Speed) (m/s)	45	AS 1170.2 <Table 3.1>
V_R (Serviceability Wind Speed) (m/s)	37	AS 1170.2 <Table 3.1>
M_d (Wind direction – westerly winds)	1.0	AS 1170.2 Clause 3.3.1
M_s (Shielding ignored)	1.0	AS 1170.2 Clause 4.3.1
M_t (Flat terrain)	1.0	AS 1170.2 Clause 4.4.1
$M_{z,cat}$ (Terrain category multiplier)	0.913	AS 1170.2 <Table 4.1>
V_{sit}, β (Ultimate) (m/s)	41	AS 1170.2 Clause 2.2
V_{sit}, β (Serviceability) (m/s)	34	AS 1170.2 Clause 2.2

2.3.2. Design Wind Pressure

Table 8: Design Wind Pressure

$P = (0.5\ \rho_{air})\ [V_{des,\theta}]^2\ C_{fig}\ C_{dyn}$		**References**
ρ_{air} (kg/m^3)	1.2	AS 1170.2 Clause 2.4.1
Vdes,θ (Ultimate) (m/s)	41	Vsit,β (Ultimate)
Vdes,θ (Serviceability) (m/s)	34	Vsit,β (Serviceability)
Cdyn	1.0	AS 1170.2 Clause 2.4.1
P (kPa) = (0.5 x 1.2/1000) $[41]^2$ x 1 x Cfig	1.009 Cfig	AS 1170.2 Clause 2.4.1
P (kPa) = (0.5 x 1.2/1000) $[34]^2$ x 1 x Cfig	0.694 Cfig	AS 1170.2 Clause 2.4.1

2.3.3. Aerodynamic Shape Factor

CASE 1: Longitudinal Wind

Internal Pressure:

$C_{fig,i} = C_{p,i} K_{c,i}$ Clause 5.2

The structure is deigned to be enclosed except for the door opening at the main entrance.

Ratio of opening to surface area = 14.66/1152 = 0.0127 > 0.5%

Ratio of opening on one surface to sum of total open area of other wall = 14.7/0 = ∞ > 6

$C_{p,i} = C_{p,e} = 0.7$ (Largest opening on windward wall) <Table 5.1(B)>

$K_{c,i} = 0.8$ <Table 5.5>

External Pressure:

$C_{fig,e} = C_{p,e}K_aK_{c,e}K_lK_p$ Clause 5.2

Windward: $h \leq 25$ m $C_{p,e} = 0.7$ <Table 5.2(A)>

Leeward: $\theta = 0°$ $\alpha = 20°$ $C_{p,e} = -0.4$ <Table 5.2(B)>

Side: $C_{p,e} = -0.65$ 0 to 15 m from windward edge <Table 5.2(C)>

Roof: h/d = 17.3/15 = 1.154 ≥ 1.0 <Table 5.3(A)>

$C_{p,e}$ = - 1.3, - 0.6 0 to 8.65 m from windward edge

= - 0.7, - 0.3 8.65 to 10 m

Area reduction factor, $K_a = 1.0$ (conservative) <Table 5.4>

External action combination factor, $K_{c,e} = 0.8$ <Table 5.5>

Local pressure factor for cladding, $K_l = 1.0$ Clause 5.4.4

Permeable cladding reduction factor, $K_p = 1.0$ Clause 5.4.5

Frictional drag forces d/h = 15/17.3 = 0.87 < 4 Clause 5.5

d/b = 15/55 = 0.27 < 4

$C_f = 0$

Table 9: Wind Load Combination – Longitudinal Wind

Location	$C_{p,e}$	$C_{fig,e}$		$C_{fig,i}$	
		Most +ve	Most -ve	Most +ve	Most -ve
Windward Wall	0.7	0.56		0.56	
Leeward Wall	- 0.4		- 0.32	0.56	

Side Wall	- 0.65		- 0.52	0.56	
Roof: 0 – 8.65 m 8.65 – 10 m	 - 1.3, - 0.6 - 0.7, - 0.3		 - 1.04 - 0.56	 0.56 0.56	

Table 10: Wind Load Combination 2 - Longitudinal Wind

Location	Combination C_{fig}		Design Wind Pressure (kN/m^2)			
	Most +ve External + Most -ve Internal	Most -ve External + Most +ve Internal	Ultimate		Serviceability	
Windward Wall	0.56	- 0.56	0.565	- 0.565	0.477	- 0.477
Leeward Wall		- 0.88		- 0.888		- 0.616
Side Wall		- 1.08		- 1.090		- 0.756
Roof: 0 – 8.65 m 8.65 – 10 m		 - 1.60 - 1.12		 - 1.614 - 1.130		 - 1.120 - 0.784

<u>CASE 2: Cross Wind</u>

Internal Pressure:

$C_{fig,i} = C_{p,i} K_{c,i}$ Clause 5.2

The structure is deigned to be enclosed except for the door opening at the main entrance.

Ratio of opening to surface area = 14.66/1152 = 0.0127 > 0.5%

Ratio of opening on one surface to sum of total open area of other wall = 0/14.7 = 0 < 0.5

$C_{p,i} = C_{p,e} = -0.3, 0$ (Largest opening on side wall) <Table 5.1(B)>

$K_{c,i} = 0.8$ <Table 5.5>

External Pressure:

$C_{fig,e} = C_{p,e}K_aK_{c,e}K_lK_p$ Clause 5.2

Windward: $h \leq 25$ m $C_{p,e} = 0.7$ <Table 5.2(A)>

Leeward: $\theta = 0°$ $\alpha = 20°$ $C_{p,e} = -0.4$ <Table 5.2(B)>

Side: $C_{p,e}$ = - 0.65 0 to 17.3 m from windward edge <Table 5.2(C)>

= - 0.5 17.3 to 34.6 m

= - 0.3 34.6 to 51.9 m

= - 0.2 > 51.9 m

Roof: $\alpha \geq 10°$ h/d = 17.3/55 = 0.31 <Table 5.3(B)>

$C_{p,e}$ = - 0.32, 0.15

Area reduction factor, K_a = 1.0 (conservative) <Table 5.4>

External action combination factor, $K_{c,e}$ = 0.8 <Table 5.5>

Local pressure factor for cladding, K_l = 1.0 Clause 5.4.4

Permeable cladding reduction factor, K_p = 1.0 Clause 5.4.5

Frictional drag forces d/h = 55/17.3 = 3.18 < 4 Clause 5.5

d/b = 55/15 = 3.67 < 4

C_f = 0

Table 11: Wind Load Combination – Cross Wind

Location	**$C_{p,e}$**	**$C_{fig,e}$**		**$C_{fig,i}$**	
		Most +ve	**Most -ve**	**Most +ve**	**Most -ve**
Windward Wall	0.7	0.56		0	- 0.24
Leeward Wall	- 0.4		- 0.32	0	- 0.24
Side Wall:					
0 – 17.3 m	- 0.65		- 0.52	0	- 0.24
17.3 – 34.6 m	- 0.5		- 0.40	0	- 0.24
34.6 – 51.9 m	- 0.3		- 0.24	0	- 0.24
51.9 – 55 m	- 0.2		- 0.16	0	- 0.24
Roof	- 0.32, 0.15	0.12	- 0.26	0	- 0.24

Table 12: Wind Load Combination 2 – Cross Wind

Location	**Combination C_{fig}**		**Design Wind Pressure (kN/m^2)**			
	Most +ve External + Most -ve Internal	**Most -ve External + Most +ve Internal**	**Ultimate**		**Serviceability**	
Windward Wall	0.80	0	0.807	0	0.555	0
Leeward Wall	0.24	- 0.32	0.242	- 0.323	0.167	- 0.222
Side Wall:						
0 – 17.3 m	0.24	- 0.52	0.242	- 0.525	0.167	- 0.361
17.3 – 34.6 m	0.24	- 0.40	0.242	- 0.404	0.167	- 0.278
34.6 – 51.9 m	0.24	- 0.24	0.242	- 0.242	0.167	- 0.167
51.9 – 55 m	0.24	- 0.16	0.242	- 0.161	0.167	- 0.111
Roof	0.36	- 0.26	0.363	- 0.262	0.250	- 0.180

Design Wind Loads

Table 13: Design Wind Loads

Location	Maximum Downward Load, w_u (kN/m)		Maximum Uplift Load, w_u (kN/m)	
	Ultimate	Serviceability	Ultimate	Serviceability
Walls	4.035	2.775	5.450	3.780
Roof	1.815	1.250	8.070	5.600

2.3.4. Other Structural Members

Analysed using SPACEGass

2.4. Design Load Combination

Limit state	Description	Combination Case on Space Gass
(G)	Permanent Action	1
(Q)	Imposed Action	2
Wu	Wind loads with varying cardinal directions	3, 4, 5, 6, 7, 8, 9, 10
[1.35G]	Permanent action only	41
[1.2G, 1.5Q]	Permanent and imposed action	42
[0.9G, Wu]	Permanent and wind action reversal with varying cardinal directions	43
[1.2G, Wu, ψ_cQ]	Permanent, wind and imposed action with varying cardinal directions	44
Serviceability [G, ψ_sQ]	Serviceability permanent and short-term imposed action	45
Serviceability [G, Wu]	Serviceability permanent and wind with varying cardinal directions	46

3. Member Design Capacity

Based on SpaceGass analysis, the critical load combination for both modules are 1.2G + 1.5Q and 1.2G + Wu + ψ_cQ. The floor members are critical under 1.2G + 1.5Q loading while the column, ceiling, and roof members are critical under 1.2G + Wu + ψ_cQ loading. The module members are checked on spacegass for their capability to bear the load combinations. Calculations are also done to justify the spacegass results.

3.1. Module 1

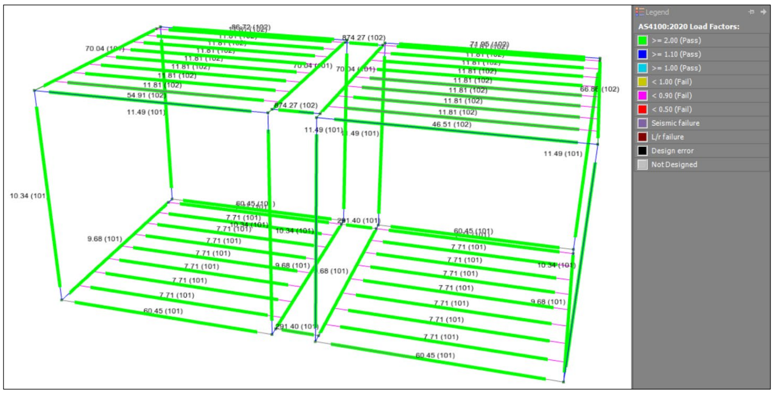


Figure 2: Module 1 SpaceGass Member Check

Based on SpaceGass analysis, all members of module 1 can withstand the critical load combination acting on the structure (shown in Figure 14). The deflection, shear force, and bending moment acting on module 1 due to the load combination is shown in Appendix 1. Detailed calculation of the member design check on the members of module 1 due to critical load combination in accordance with AS4100 is shown in Appendix G.

3.2. Module 2

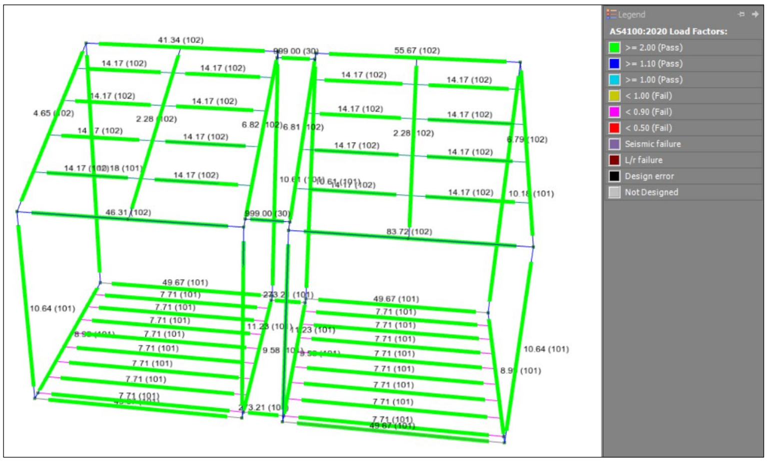


Figure 3: Module 2 SpaceGass Member Check