Rapid Rebuild Ukraine

MODULAR RESIDENTIAL BUILDINGS FOR UKRAINE RE-CONSTRUCTION

Modular residential buildings for Ukraine re-construction

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1. Benefits of modular constructon for Ukraine

Modular construction uses 3 dimensional units that are prefabricated and fully fitted out in factories, which leads to a rapid construction system.

Implementation

It is key to involve the modular manufacturer at the earliest stage to maximise the benefits of off- site construction. Repetitive construction improves the interface between the modules and the site-based elements, such as cladding and services.

Modules are delivered with bathrooms, kitchens, heating, decorated and fully serviced.

Balconies may be incorporated in the modules in the factory and thus reduces work onsite.

External cladding, staircases and walkways may also be manufactured in the factory which would further reduce construction time.

Site Management

Construction periods are reduced by 60% to 80%, which leads to savings to the contractor and client.

Site management and site facilities costs are reduced by 30 to 40% in comparison to traditional construction. Module installation rates of 6 to 8 per day may be considered to be typical. No downtime in cold weather.

Design

The detailed design work is done by the modular supplier. Module sizes are designed to satisfy local Building Codes and spacing requirements.

Modules are tied together so that they act structurally as a stable unit. Modules sizes may be varied using the same basic system and openings may be created in the walls to combine modules.

Modules are relatively lightweight so that they can be supported on a steel or concrete framed podium which provides open plan space at ground floor.

Modular buildings are de-mountable.

Less Waste

Working under controlled factory conditions minimises wastage by efficient material usage. Prefabrication only creates 1/10 of waste associated with site-based construction methods.

Importantly, steel waste can be recycled.

Less Transportation & Disruption

Prefabrication reduces the number of vehicle movements and decreases local road traffic. Deliveries and installation can be planned with local residents to avoid busy periods.

Construction products account for around 20% of commercial vehicle journeys and so fewer movements reduce carbon emissions .

Quality Control and Safety

Superior quality control because building is precision engineered offsite.

Modular construction uses less than one quarter of the number of site operatives of traditional methods.

Site safety is greatly improved by increased mechanisation and more of the work is done in safe factory conditions.

Air tightness, energy efficiency and sound proofing are greatly improved.

Future maintenance is reduced .

Modular buildings can be dismantled and re-used to maintain their asset value.

Rapid construction for regional factories

To meet the challenge of re-building destroyed houses and apartments, regional factories are required which are capable of producing 30,000 modules a year. Travel distances of less than 200 km to the project sites are recommended.

The factories may be 50,000 m2 in area and employ 1000+ skilled people.

2. References - existing projects

The following images show modular buildings constructed using light steel modular units in the UK.

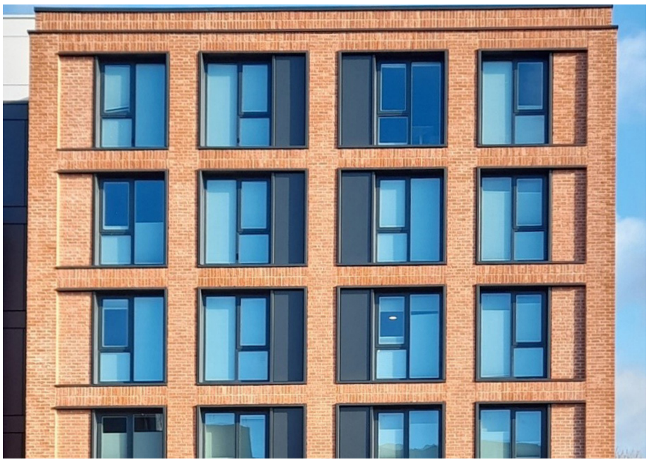


Fig.1 Student residence with brick facade, UK

Fig.2 Modular housing with partial brick facade, London

Fig.3 Courtyard view of modular residential buildings with large balconies, UK

Fig.4 Residential building with apartments for rent, South London

Fig.5 Residential building with restaurant and office space at ground floor, Manchester

Fig.6 Terraced housing with attached balconies, Twickenham, west London

3. Design of lightweight modular system

Introduction

A modular system has been devised that is manufactured from cold formed steel sections. The modules have load-bearing side walls and are cellular in form.

They are suitable for housing, apartment buildings and hotels in which the size of the module is determined primarily by ease of transportation.

Two modules may be placed side by side to create a single bedroom apartment, and three modules create larger apartments. The lightweight nature of the modules is such that they typically weigh less than 10 Tonnes and can be assembled on site with mobile cranes.

The target range of application is in buildings of 3 to 6 storeys in height where the load-bearing nature of the C sections is superior to that of modules made of timber construction. The nominal internal width of the modules is 3.3m, although both the width and length of the modules can be varied. The modules can also be manufactured with an integral balcony, and potentially also with an integral corridor. Stairs and lifts may also be manufactured in modular form although more flexibility is provided in the lobby areas if they are built from a conventional steel frame.

Design Criteria: structural and fire resistance

The following design criteria were adopted in the concept design of a lightweight modular system:

• Width of module up to 3.3m internal and 3.6m externally, although narrower modules can can be manufactured using the same system.

• Internal module heights are 2.4m to 2.6m.

• Floor and ceiling heights are 500mm to keep to the minimum sensible module height for planning purposes.

• Building heights are up to 6 storeys (or 18m approximately), although taller buildings can be designed using thicker steel.

• 1.5 hour fire resistance is provided by 2 layers of 15mm plasterboard on the internal face of the wall and ceiling.

• Wind and weather resistance is provided by a suitable sheathing board on all external faces of the modules.

• Maximum opening width of 2.4m in the side walls of the modules (these are load-bearing walls).

• Projecting integral balcony of up to 1.2m.

• Windows of up to 2.4m in the façade wall.

• Any type of lightweight cladding may be attached to the modules. Brick cladding may be ground supported up to 4 storeys height.

• Any type of lightweight roofing system may be used, for example, using a slightly pitched timber roof or steel purlins spanning between the module walls.

Structural Module Design

The following C sections are used in the module design:

• C sections (200 x 50 x 1.6 mm) in the floors at 400mm centres.

• C sections (150 x 50 x 1.2 mm) in the ceiling at 600mm centres.

• C sections (100 x 50 x 1.6 mm) in the walls at 600 mm centres placed singly for modules on the upper floors and in pairs on the lower floors.

• U sections (205 x 50 x 1.6 mm) around the periphery of the module into which the C section floor joists are fitted.

• U sections (155 x 50 x 1.2 mm) around the periphery of the module into which the C section ceiling joists are fitted.

• Corner angles using 100 x 100 x 10mm steel which provide for the connection between the modules.

• The modules are connected at their corners by 100mm wide by 10mm thick steel plates with 20mm in diameter, high strength bolts that provide for tying action.

• The modules are lifted from their corners.

All steel is fy = 350 N/mm^2. The weight of steel in the modules is calculated as approximately 50 kg/m^2 floor area. The finished weight of the module is estimated as 3 kN/m^2, which for a module of 35m^2

floor area is approximately 10 tonnes.

The imposed floor loading is taken as 2 kN/m^2. The wind loading is variable but is taken nominally as 1 kN/m^2.

Because of the lightweight nature of the modules, an equivalent horizontal acceleration of 5% gravity can be resisted by the modules in seismic events.

Openings of 2.4m width may be created in the side walls, and pairs or triple Cs are placed in the walls to transfer the required compression loads. The U sections at the edge of the floor cassettes act in bending to transfer the floor loads across the openings.

The modules are sheathed with OSB, cement particle board, plywood or MgO board etc. to provide suitable resistance to in-plane wind forces. The design in -plane shear force of these sheathing boards is taken as 4 kN/m approx. For buildings taller than 6 storeys high, it may be necessary to rely on additional bracing around the stairs and lift core for stability.

Fig.7 Modular installation in Lewisham, London

Fig.8 Installation of module with partially open sides

Residential building units

4. Residential building units

The aim is to design and manufacture pre-fabricated volumetric modules which are delivered to site fully serviced and fitted out with bathroom and kitchen fittings, doors, windows, finishes and internal decorations, and, with suitable interfaces to external cladding and roofing.

The parameters of the modular construction have been carefully considered so that, working with the manufacturer from the outset, the module itself has evolved to create a high quality product. Through improved construction and design, the client and the design team are able provide generous space standards and higher internal and external construction quality than is obtainable by traditional methods.

Fig.9 4-storey student residential building in Oxford

Building Types

The following building types may be designed using the lightweight modular system:

• Apartments in 1 , 2 and 3 module configurations.

• Hotels –single room modules.

• Mixed use residential and office/ retail buildings or car parking by building the modules on a podium.

• Building extensions such as modules placed on an existing flat roofed building.

• Communal buildings and sports facilities eg changing rooms.

• Demountable and temporary use buildings.

Fig.10 12-storey hotel in Wembley, North London

Fig.11 Demountable refuge accommodation for the YMCA, South London

Proposed modular design

A multi-storey apartment building may be designed using 2 modules per apartment (single bedroom for 2 people) that can be extended to 3 and 4 modules for families. Each apartment includes private balcony space.

The size of each module has been optimised from the point of view of transportation to site, and flats themselves are planned to utilize the minimum number of similar sized modules.

The flats are designed using the maximum 3.6m wide module that it is possible to transport on highways (although they must be checked for the particular location). The modules are 7.2m long but may be manufactured up to 12m long, which is the sensible maximum.

The modules provide the accommodation space, service routes, balconies and potentially the corridors as part of the modules. The modules are weather tight in the construction and permanent conditions. The lobby, stairs and lifts are constructed conventionally as they as off the critical path.

A 2-bed flat plan form was developed which maximizes the internal space and external amenity of each dwelling. This was achieved in such a way that they could be joined together with minimal work on site, being linked only by a single door.

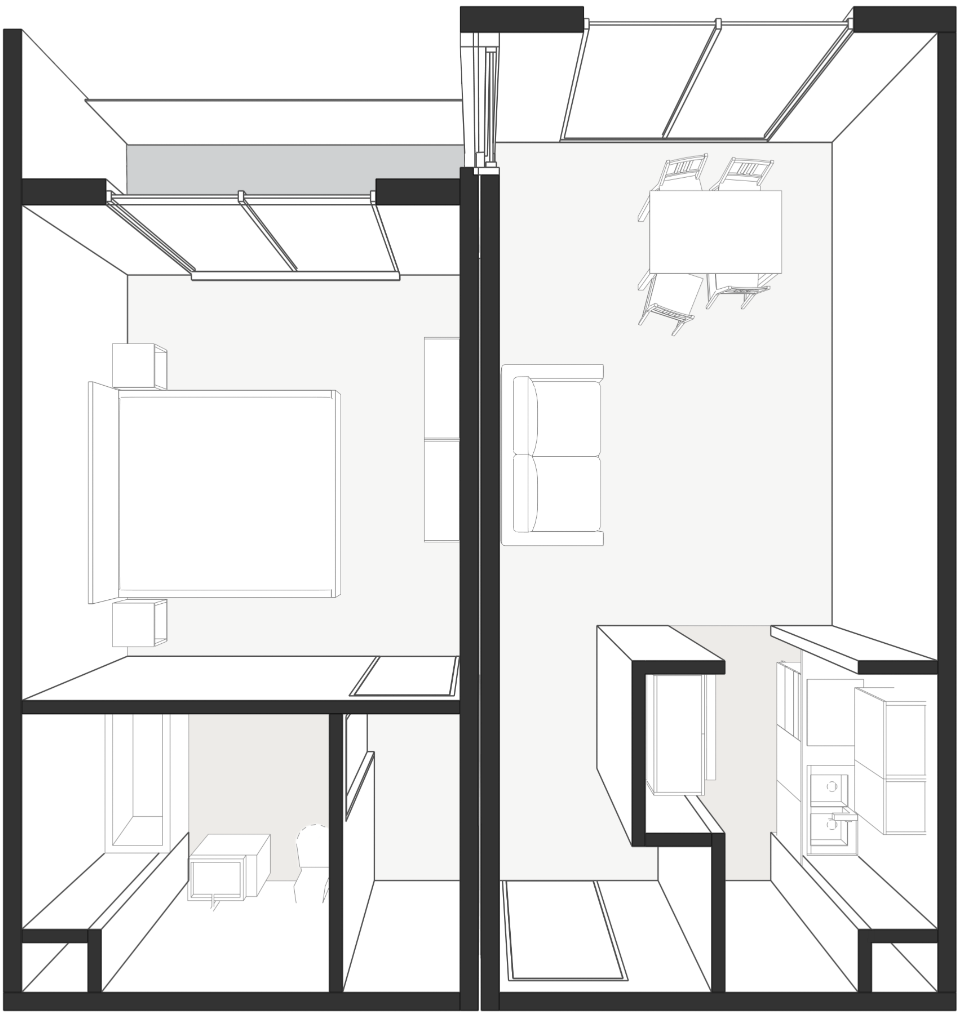


Fig.12 1-Bedroom apartment _ Perspective view / out of scale

Typical space planning standards are here presented for comparison purposes.

The plan form of two adjacent, similar sized modules, one with an integral balcony is shown below. Access is provided via a central corridor.

Fig.13 Space Planning Standard

Apartments or other dwellings on one floor		
1b1p	1 bed space	38 m²
1b2p	2 bed spaces	47 m²
2b3p	3 bed spaces	60 m²
2b4p	4 bed spaces	69 m²

Fig.14 1-Bedroom apartment _ Floor plan / Scale 1:100

Alternative building layouts

The following images show two potential building arrangements for conceptual apartment blocks, using modular units.

The first option uses a linear symmetrical arrangements, with a central corridor and a central core of services, including lift, stairs and service risers.

Fig.15 Conceptual building layout 1 _ Floor plan / Scale 1:200

Fig.16 Conceptual building type 1 - Main elevation / Scale 1:200

The second option shows a corner arrangement, which features a different layout providing single aspect for all units and dual aspect rooms for the gable units.

Such layouts can accommodate different unit types, such as:

- 1-bedroom apartments (using 2 modules)
- 2-bedroom apartments (using 3 modules)
- Studio apartments (that can be located opposite to the service core)

Fig.17 Conceptual building layout 2 _ Floor plan / Scale 1:200

5. Performance Specifications

The following general performance requirements were adopted in the design.

Services

A 500mm x 375mm service zone is provided in the corners of all the modules next to the corridors which houses the 'wet' services in a vertical riser. Suitable 'fire stops' are introduced between the modules. Electrics and telecoms are routed through a drop ceiling in the corridor zone. Slim-line chiller units may be installed in the ceiling zone of the modules.

Acoustics

The double layer construction of the separating walls and floor –ceiling combination ensure that excellent acoustic performance is achieved. Tests have shown that the standard modular specification achieves 60 dB airborne sound reduction and an additional layer of plasterboard on each face adds 3 dB to this sound reduction.

Fire safety

Fire resistance is achieved by multiple layers of plasterboard on the inside face of the walls and ceiling of the modules with mineral wool between the C sections. Two layers of 15mm plasterboard are required for standard cases with three layers for taller buildings. Fire resistant sheathing boards, such as MgO boards or cement particle boards (CPB) are required to prevent fire entering the modules from outside. Fire stops in the form of mineral wool 'socks' are placed between the modules to prevent fire spread.

An additional sand-cement screed of 65mm may be placed on the floor boarding to provide additional fire resistance and to route heating and cooling pipes, if required. This will add to the load on the joists and walls which may require use of more closely spaced or thicker C sections.

Thermal performance

A variety of cladding systems may be used. Externally, closed cell insulation is attached to the modules in addition to mineral wool between the Cs to provide the required U value. 75mm of closed cell insulation and 100mm of mineral wool achieves a U value of 0.2 W/m^{2}K.

Air quality

Air management systems can be installed to maintain air quality in the ceiling and bathroom zones. Ducts may be routed through the ceiling or in a shallow zone below the ceiling.

Seismic resistance

The modules are robust structurally and are resistant to seismic actions. Potential loss of support to the modules is resisted by tying action between the modules. The modular system has been designed for horizontal forces in seismic events equivalent to 10% of the self-weight of the modules. Depending on the seismic zone and building height, additional bracing may have to be introduced around the stairs and lifts or in the gable walls.

Fig.18 Installation of module from a protective cage

6. Modular structure

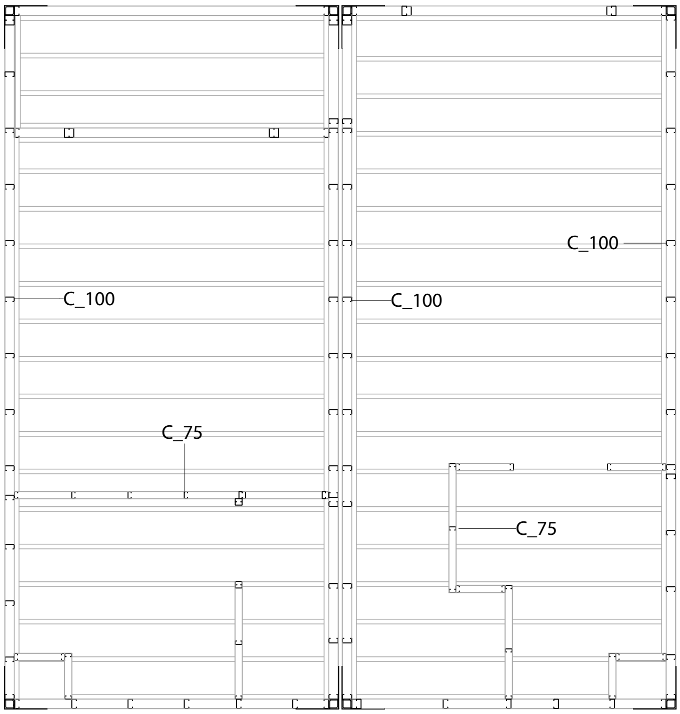


Fig.19 Wall structure - Plan layout / out of scale

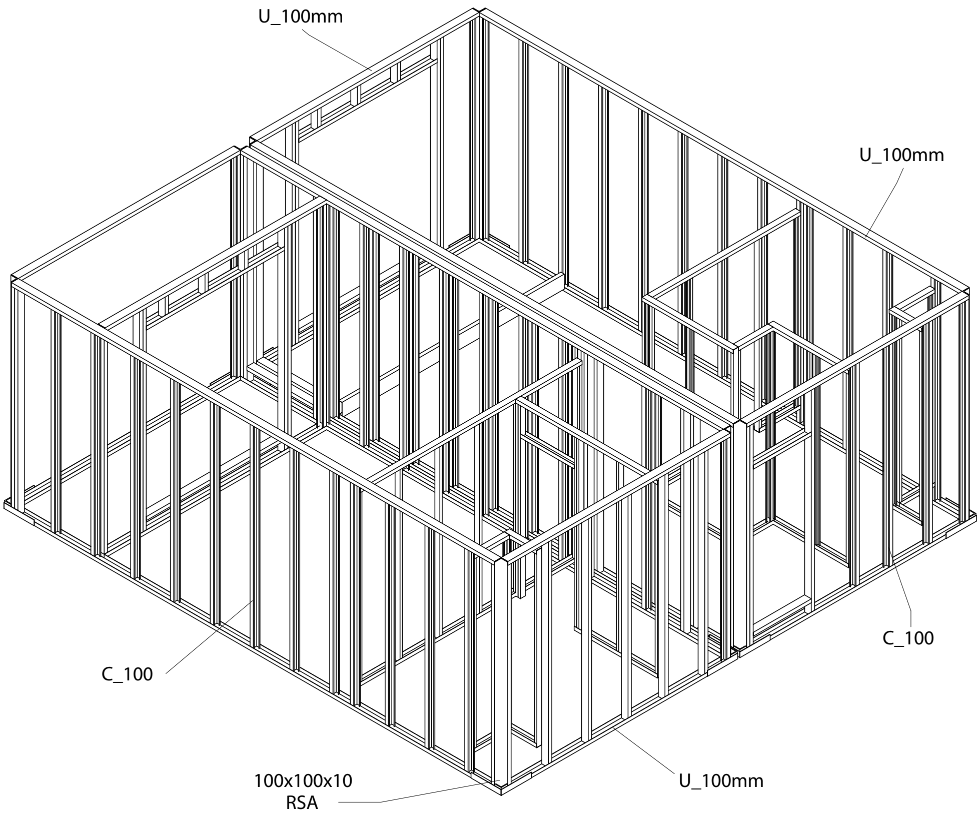


Fig.20 Wall structure - Axonometric layout / out of scale

Modular structure: floors

The layout of the C sections in the floors and ceilings is shown below. The C sections in the floors are 200mm deep x 1.5mm thick steel, placed at 400mm spacing.

The floors are manufactured as cassettes with U sections at their ends which are connected by screws to the walls.

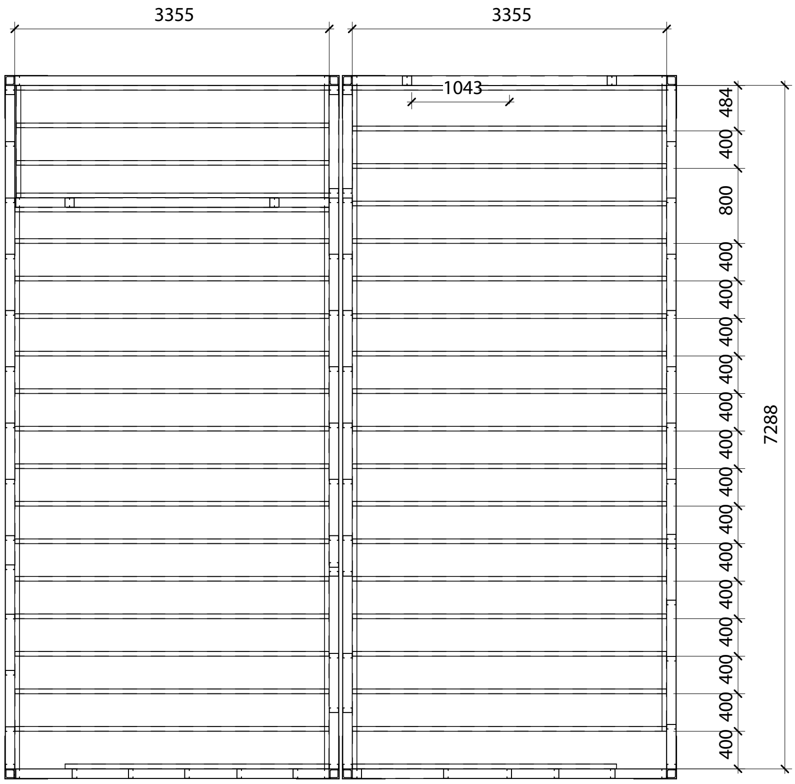


Fig.21 Floor structure - Plan layout / Scale 1:50

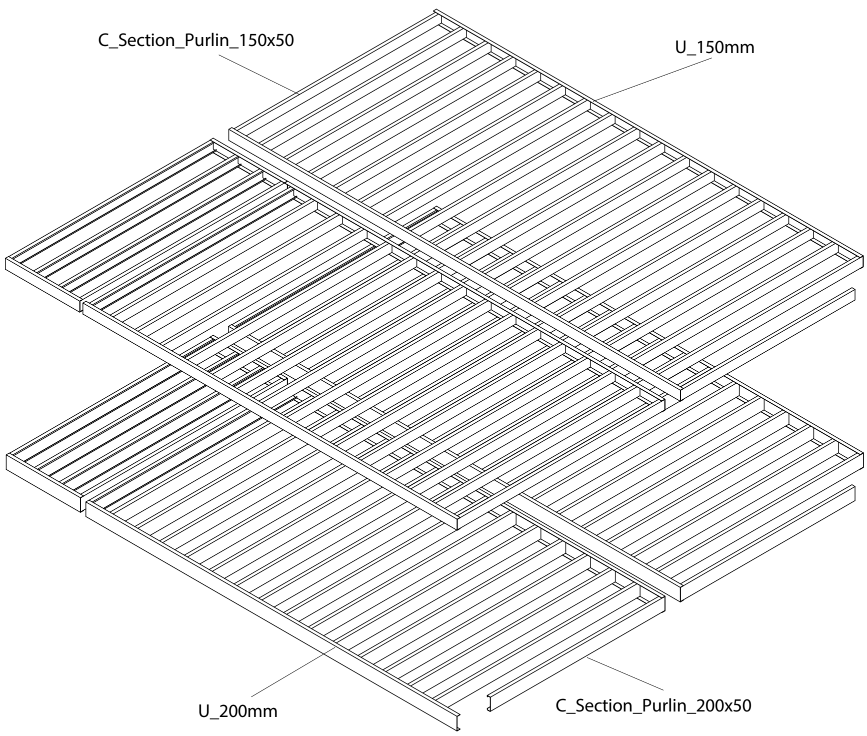


Fig.22 Floor and ceiling structure - Axonometric layout / out of scale

Modular structure: elevations

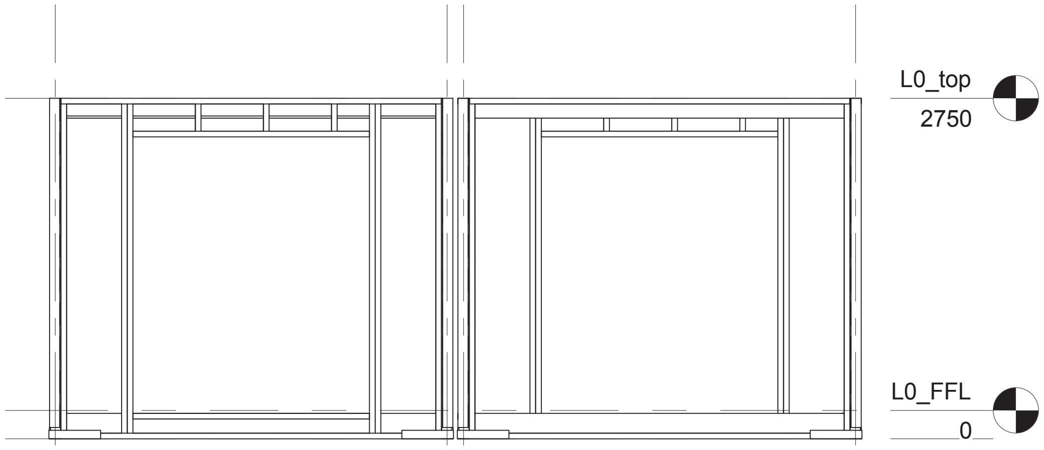


Fig.23 Modular Structure - North Elevation / out of scale

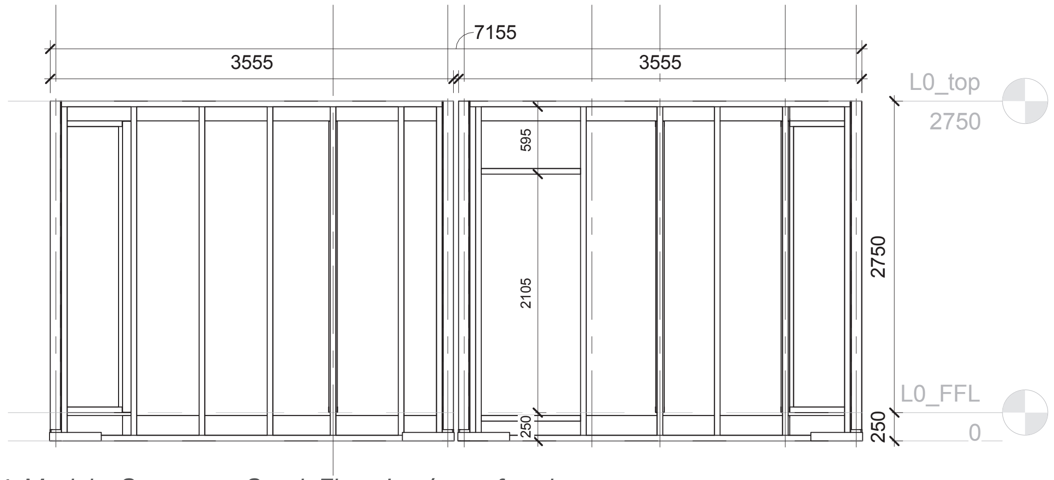


Fig.24 Modular Structure - South Elevation / out of scale

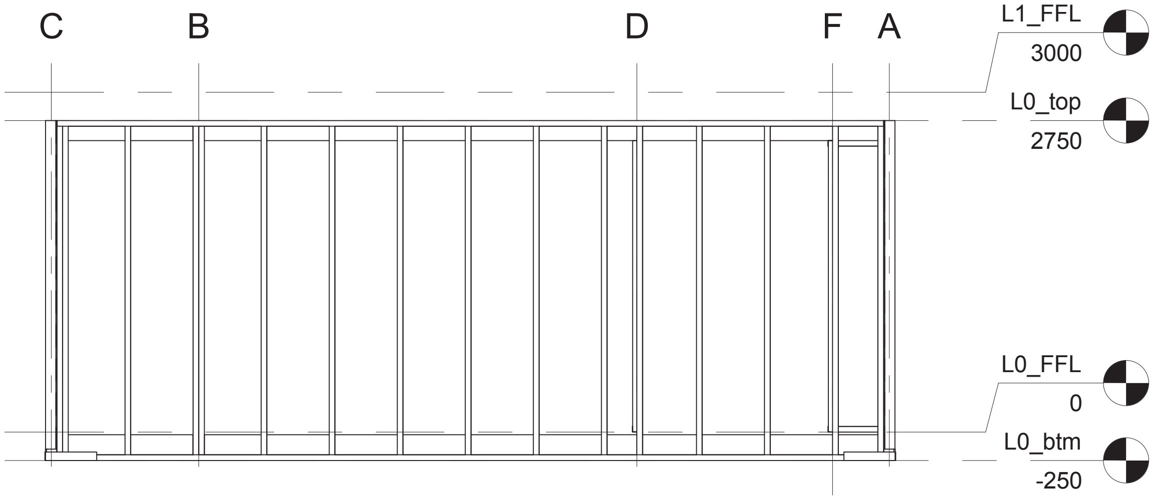


Fig.25 Modular Structure - West Elevation / out of scale

Modular structure: summary of quantities

The quantity of steel in a typical module is presented below:

Fig.26 Profiles Schedule

Count	Profile type	Profile section
48	Angle-Corner of modules	100x100x10 rolled section
102	C Sections for internal walls	C 75
276	C Sections for external walls	C 100
117	C Sections for ceiling	C 150x50
117	C Sections for module floor	C 200x50
66	U Section for edge to internal walls	U 75mm
78	U Section for edge to module walls	U 100mm
18	U Section for edge to ceiling joists	U 150mm
18	U Section for edge to floor joists	U 200mm

Fig.27 Total quantities in a typical module

Elements	Weight
Steel weight in walls and corners	700 kg
Steel weight in floors and ceiling	770 kg
Steel usage per module	1470 kg
Intensity of steel use	54 kg/m^2

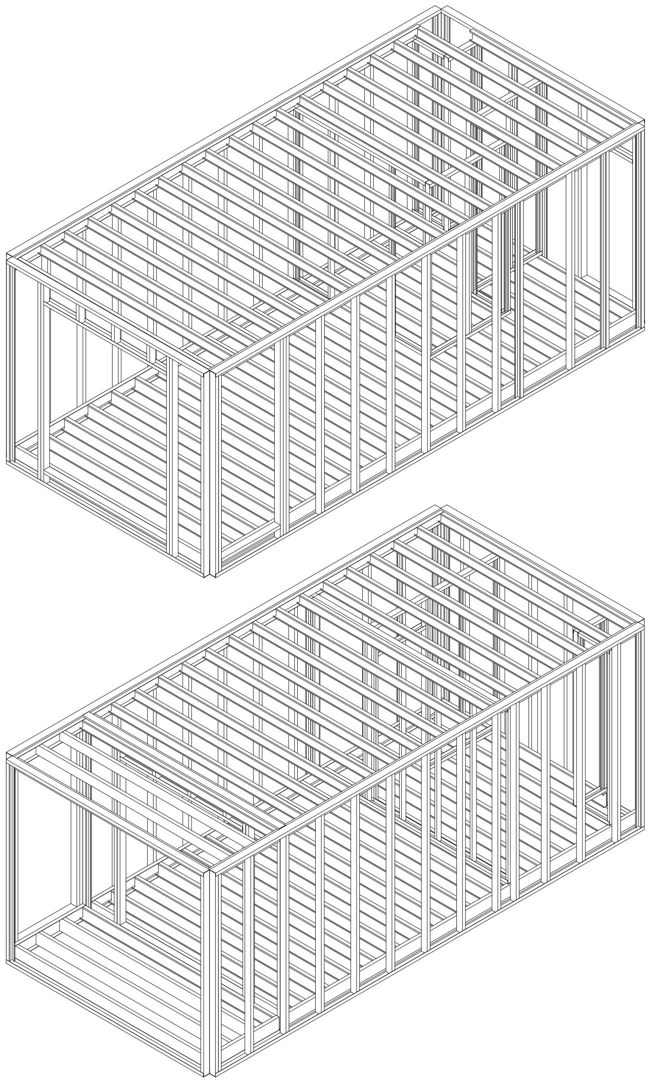


Fig.28 Assembled modules _ axonometric view / out of scale

Modular structure: details

The details of the proposed modular system are shown below:

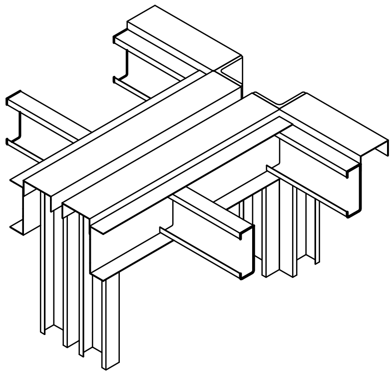


Fig.31 Junction Detail 1 / scale 1:20

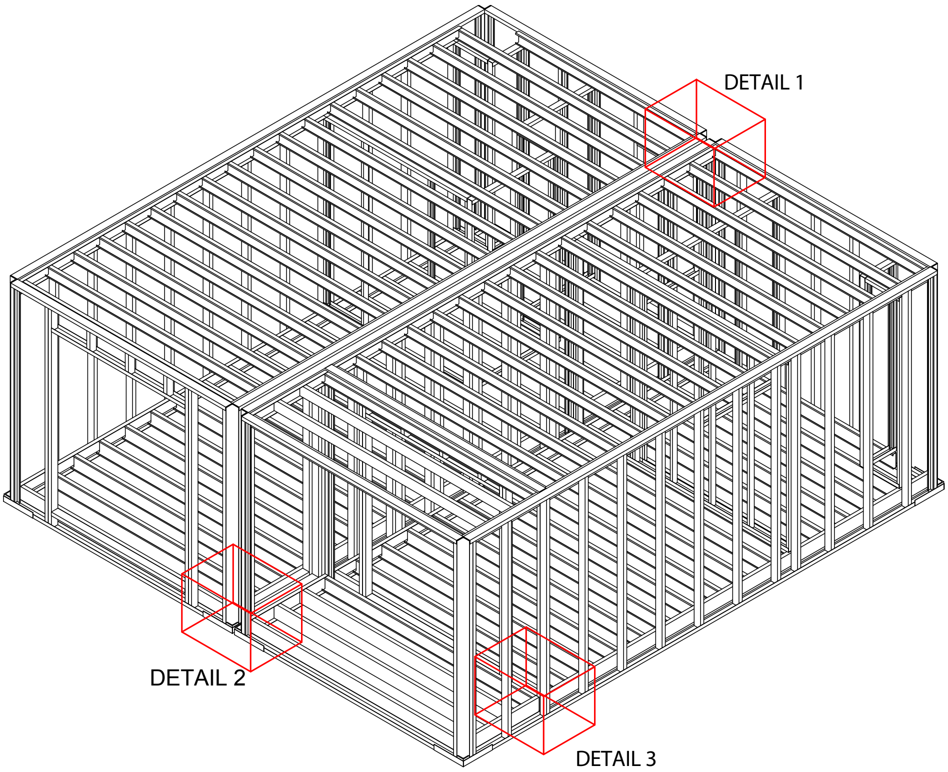


Fig.29 Junction Detail 2 / scale 1:20

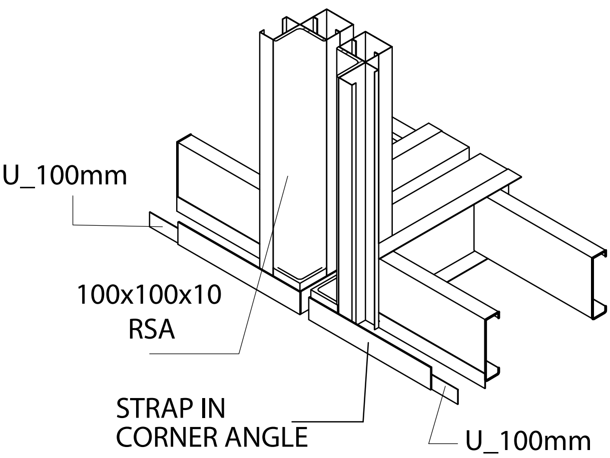
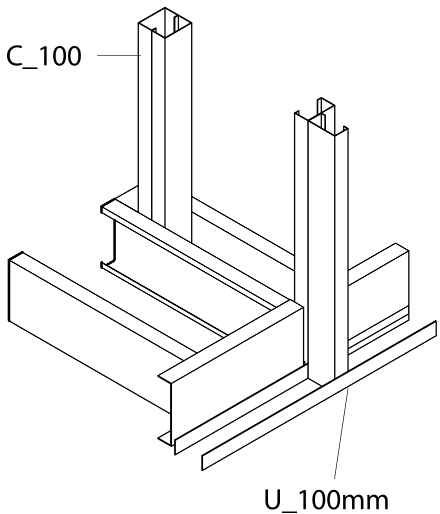


Fig.30 Junction Detail 3 / scale 1:20



Micro-apartments for central urban locations

7. Micro apartments for infill building

The second part of the proposal addresses the design of micro-flats for rental in urban locations. These buildings are often located in infill sites with street frontage and are 4-6 storeys high.

Reference: Y:Cube, London

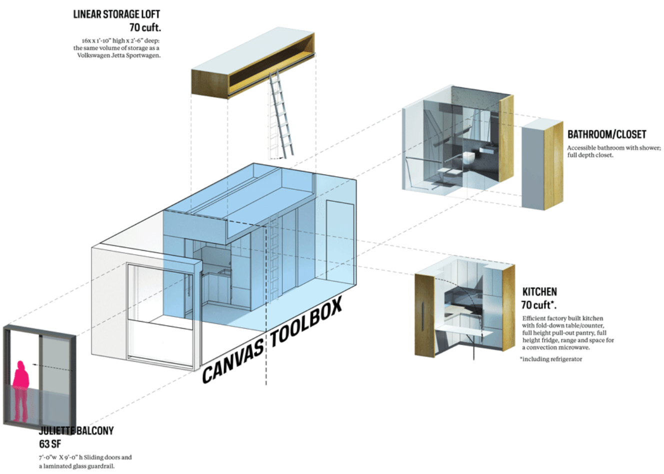
Rogers Stirk Harbour + Partners, with YMCA London South West, developed an low-cost and innovative housing solution, providing self-contained and affordable starter accommodation for young people. The Y:Cube units are 26m^2 one-bed studios, for single occupancy, that arrive on site as self-contained units. Each unit is constructed in the factory with all the services already incorporated.

Reference: My Micro NY, New York

Carmel Place (My Micro NY) is a modular, micro-unit residential building project from nArchitects and Monadnock Development. Designed to accommodate the city's growing small household population, it gained increased popularity among cities facing an affordable housing crisis .

The building provides 55 loft-like rental apartments, 25-35 m^2 net, and complemented by generous shared amenities, setting a new standard for micro-living. The project has been watched closely as a new housing prototype in NYC, and for its groundbreaking use of modular construction.

Fig.32 Y:Cube project in south-west London. Design concept (left) and completed building. (right)



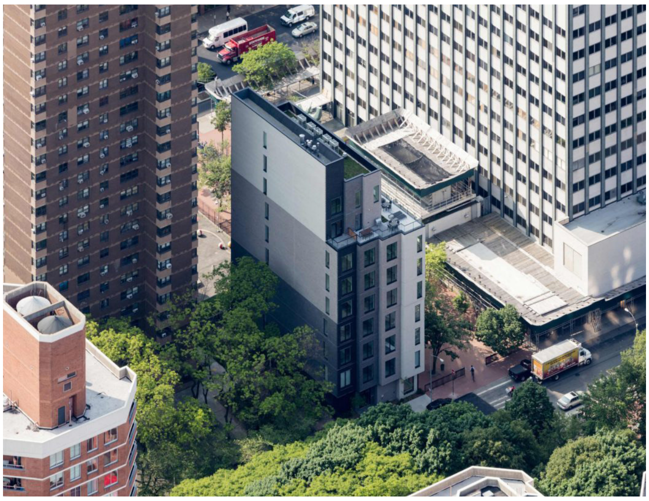


Fig.33 Carmel Place (My Micro NY) project. Exploded axonometric of typical unit (left) and completed building (right).

Alternative plan forms

Three alternative plan forms were developed to show possible arrangements for different frontage widths for infill buildings. Option A corresponds to a 21.6m width (6 modules), whereas Option B is 18m wide and Option C is 10.8m wide, corresponding to 5 and 3 modules, respectively.

All plan options include single-aspect studio apartments, each occupying one module. For the wider plan forms, two-bedroom apartments are also included, taking-up 3 modules to provide for two spacious bedrooms, a separate open plan kitchen / living room area and plenty of storage space.

Plan form A

This plan form includes:

4 studio apartments for single occupancy

2 two-bedroom apartments for 2 or 3 people.

The units are distributed symmetrically around a central corridor. A service core with stairs, lift, service risers and storage space, is locate centrally on the back elevation. This frees up the front elevation for valuable commercial/retail spaces at the ground floor and views at the upper floors.

The lower depth of the service core, compared to the steel frame modules, creates an opportunity to locate private balconies within the depth of recess on the rear elevation.

Plan form A - Room Schedule

STUDIO APT	23.3 m²
Studio	20.3
Bathroom	2.5
Storage	0.5

STUDIO APT	23.3 m²
Studio	20.4
Bathroom	2.9

STUDIO APT	23.6 m²
Studio	20.8
Bathroom	2.8

STUDIO APT	26.5 m²
Studio	20.3
Bathroom	2.8
Storage	0.5
Balcony	3.4

2-BED APT	80.6 m²
Living	23.3
Corridor	8.3
Storage	2.9
Bedroom	17.7
Bathroom	4.1
Bedroom	17.7
Bathroom	4.1
Balcony	2.5

2-BED APT	78.1 m²
Living	23.3
Corridor	8.3
Storage	2.9
Bedroom	17.7
Bathroom	4.1
Bedroom	17.7
Bathroom	4.1

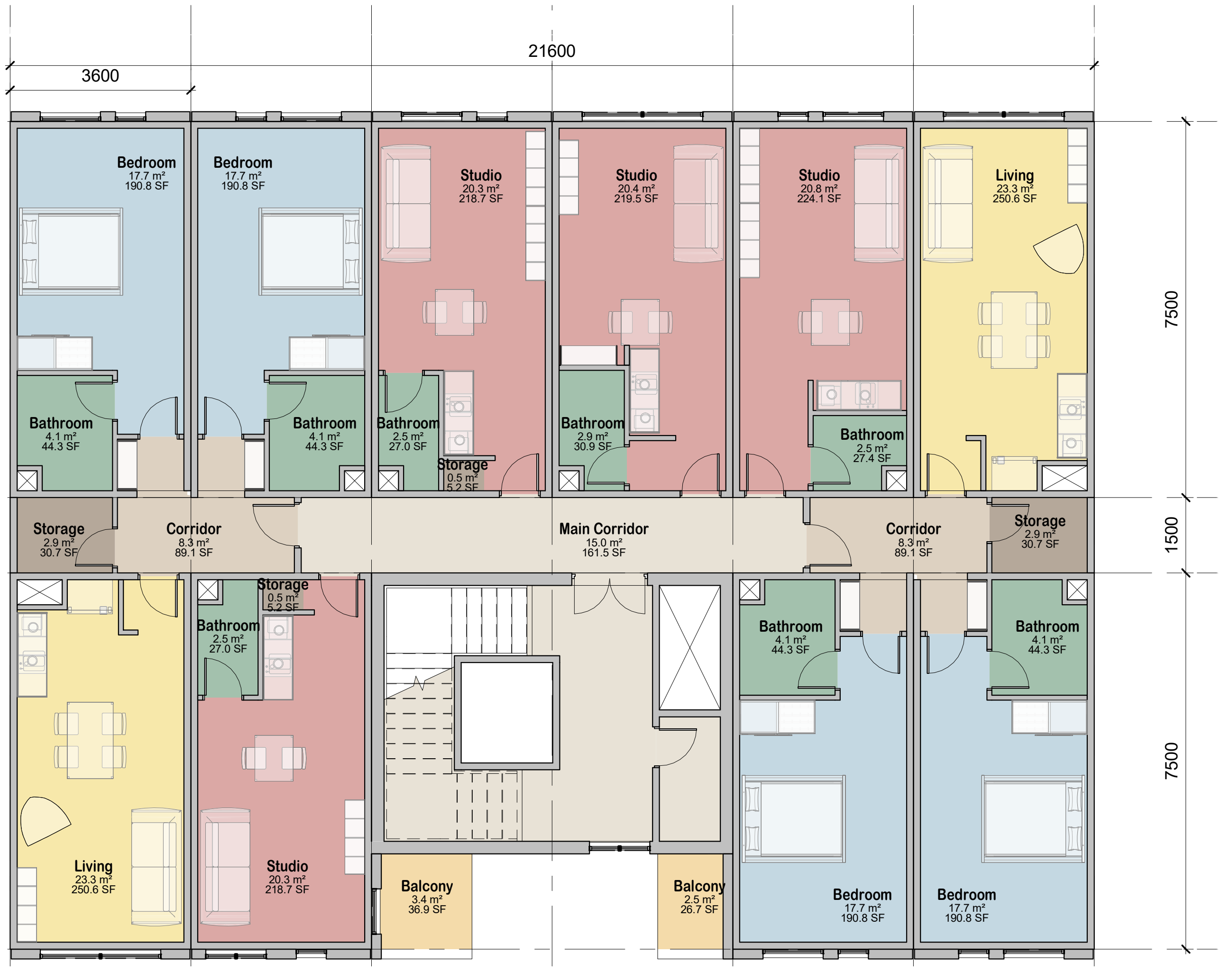


Fig.34 Conceptual building layout for infill building no 1 _ Floor plan / out of scale

Plan form B

This plan form is adapted from the wider option A by adding a transverse module below the core in order to increase floor efficiency.

The module contains a compact studio apartment, accessed from the stair core and facing onto the rear elevation.

This plan form includes:

6 studio apartments for single occupancy
1 two-bedroom apartments for 2 or 3 people.
However the design of each floor can be easily rearranged to achieve a different mix of units.

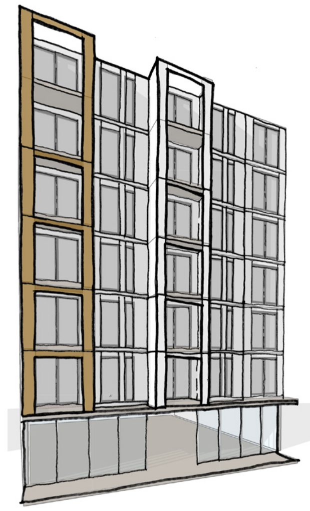


Fig.35 Main elevation sketch

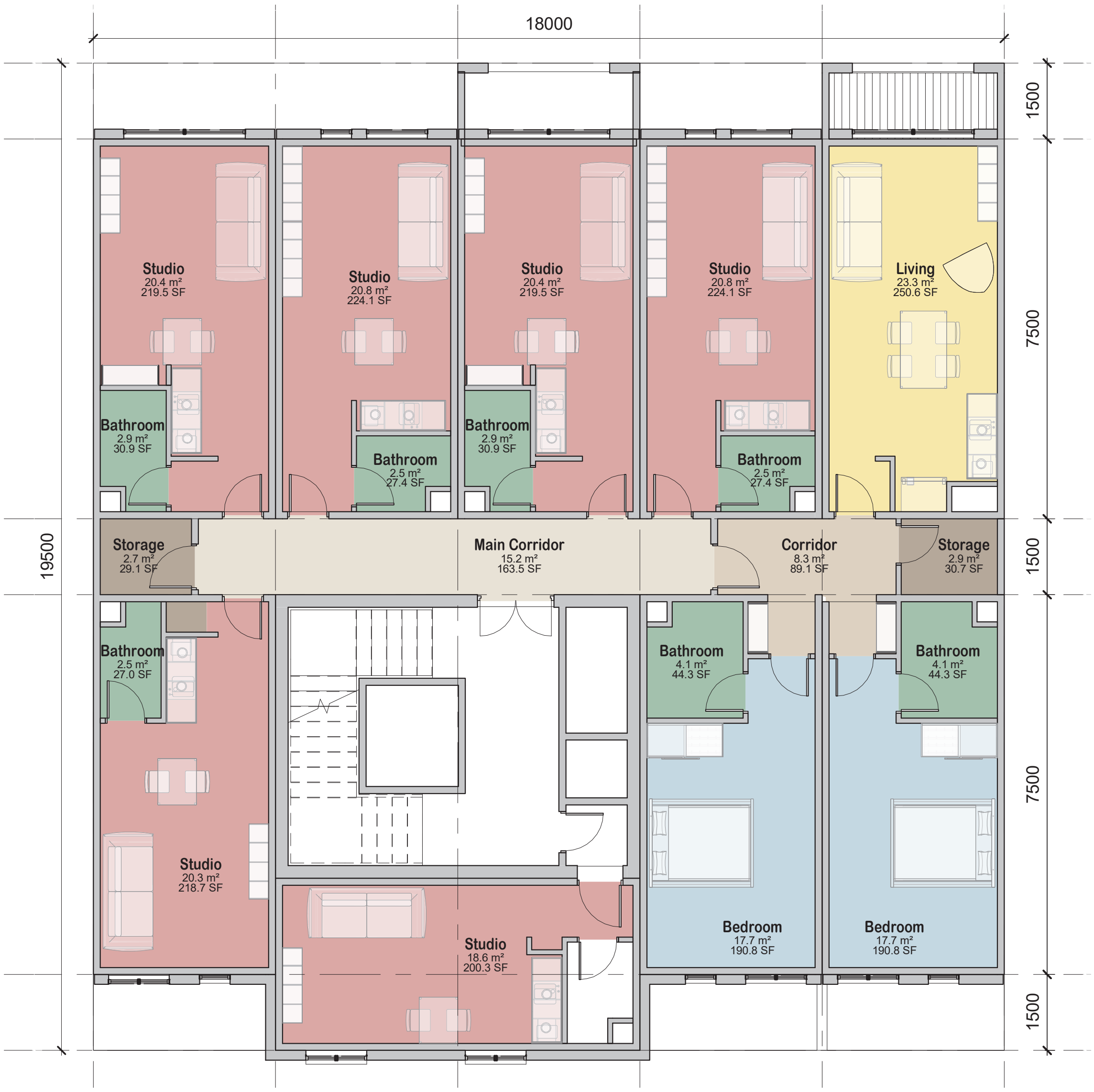


Fig.36 Conceptual building layout for infill building no 2 _ Floor plan / scale 1:200

Plan form C

This plan form consists of 5 studio apartments, each with a balcony.

A narrower, deeper core (3.6m x 9m) optimises the floor plan to achieve higher efficiency space. The core may also be manufactured in modular form for medium-rise buildings but is in reinforced concrete for taller buildings.

Balconies on front and rear elevations are manufactured as part of the light steel frame modules, which are 9m long.

Fig.38 Main elevation sketch

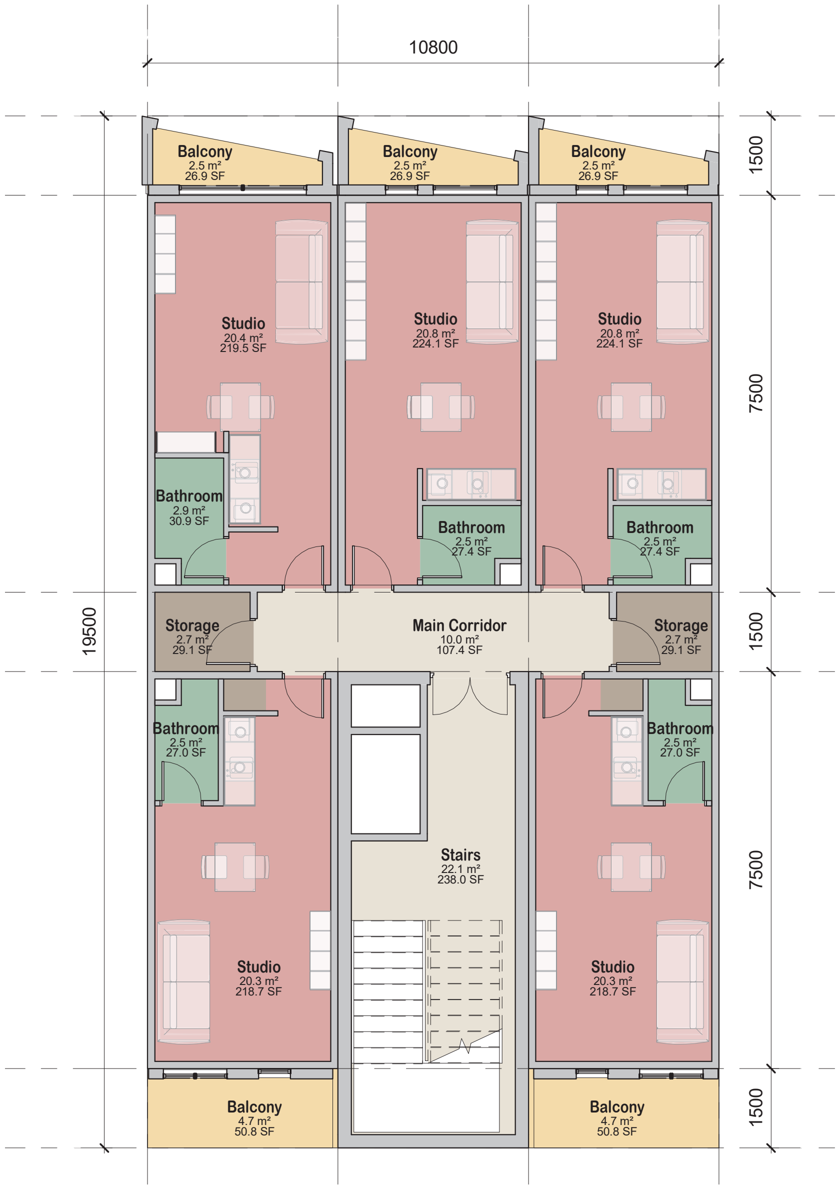


Fig.37 Conceptual building layout for infill building no 3 _ Floor plan / scale 1:200

8. Study on arrangement of standard modules building

Plan form D

This alternative plan form provides a combination of three modules sized with a 2:1 ratio, i.e. each 3600mm wide and 7200mm long. The layout allows for a two-bedroom apartment suitable for a family of 4 people, with two large bedrooms and sufficient storage space.

All modules have a 1800mm wide full height window at one end and a door and service riser at the other end, in order to give the maximum flexibility of use.

The apartment can be accessed via the kitchen area from a central core comprising lift, stairs, storage space and service risers.

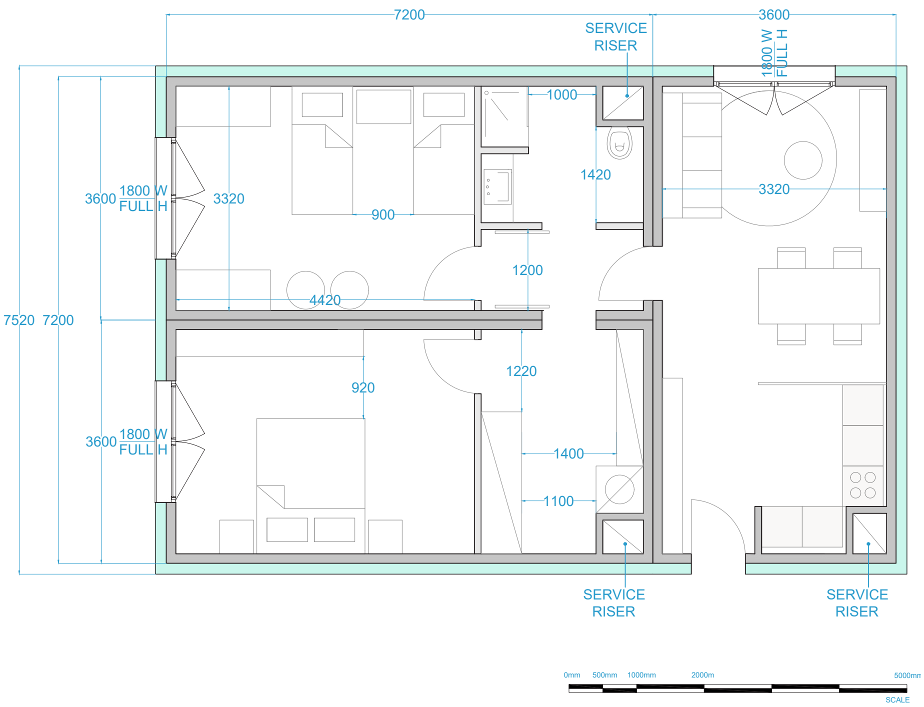


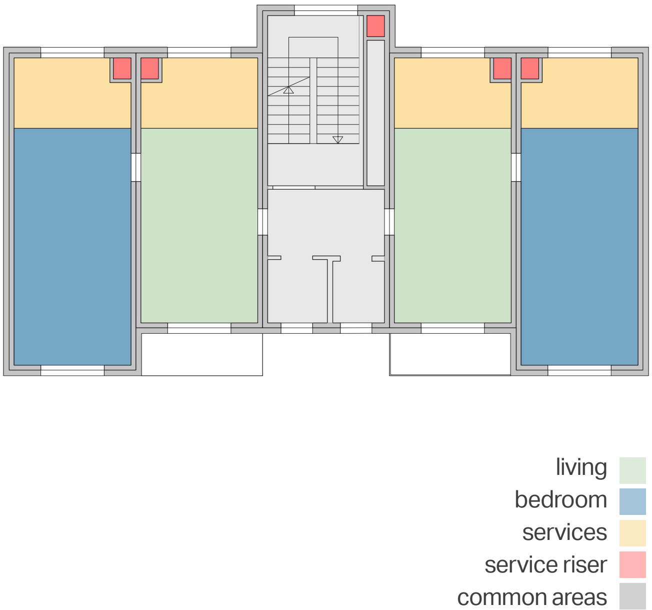
Fig.39 Plan form of assembly of 3 modules manufactured in 2:1 ratio

Plan form E

This plan form is adapted from plan form A, and offers the option of integrating a balcony using coupled modules of different lenght (7800mm and 9000mm or the same lenght including an integral balcony).

The stair / lift module is the same size as the room module.

Both plan forms D and E can be distributed around a central narrow core (similarly to Option C), which can be manufactured in modular form or in reinforced concrete, and are suitable for 3- to 6-storey residential buildings.



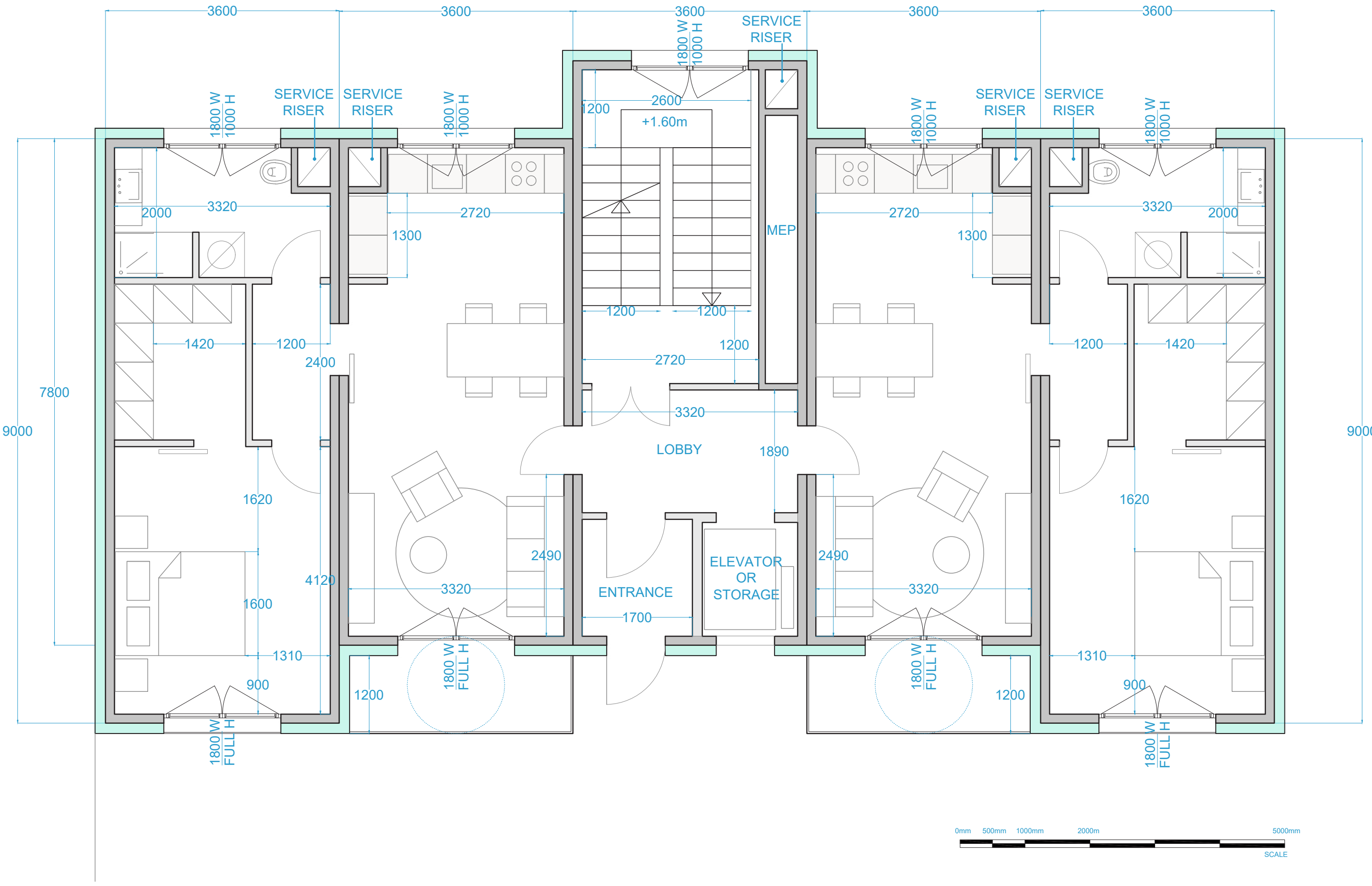


Fig.40 Plan form of building using 5 modules, one being a stairs/lift module

RAPID REBUILD UKRAINE

Mission Statement

The rapid re-building of Ukraine will require an unprecedented scale of construction of housing and residential buildings using new technologies based on off-site manufacture, and modular construction in particular. This will require construction of large regional factories each capable of producing up to 30,000 modules a year with an Innovation Hub that drives the design, automated manufacture and procurement process. This manufacturing output is required on a scale not seen in Europe, and Ukraine will lead the way in this innovative technology.

The initiative RapidRebuildUkraine is aimed at building capabilities and manufacturing infrastructure in modular construction in Ukraine, including pilot projects and tests to satisfy Ukrainian functionality requirements and to demonstrate the rapid building process and cost-effectiveness.

Our group of specialists and academics in the field of modular construction is able to provide the required expertise to assist Ukraine in this World-leading initiative.

Rapid Reconstruction

'Ukraine Rapid Damage and Needs Assessment' by the World Bank/EU (2nd Report March 2023) states that 1.4 million houses and residential buildings have been damaged, of which 500,000 have been destroyed and will have to be re-built to high quality. The World Bank estimates that the housing rebuild programme will be at least $70 billion. This will require re-building on a huge and rapid scale.

Housing Needs

Of the 500,000+ new housing and residential units required in Ukraine, 20 to 30% could be in modular form and each house or apartment comprises 2 to 4 modules. The total production requirement over 5 years would be 60,000 to 80,000 modular units a year and this would require construction and setting up of 2 to 4 advanced regional factories to serve the most affected Oblasts.

A 3 to 5 storey modular building consisting of 30 to 80 modules would take only 6 to 8 weeks to manufacture and construct, provided the factory infrastructure is set up first. An advanced regional factory to produce modules could be 50,000 m2 in floor area and should be within 200 km of the main areas of housing need. It would require a suitable level of automation and Building Information systems (BIM) that would be at the heart of the design, manufacturing, construction and facilities management process. The buildings would have safe refuge areas and would aim to be 'nearly net zero' in terms of their energy strategy.