

Building Design Using Modules

Introduction

The use of modular and other lightweight forms of building construction is increasing. The benefits of off-site prefabrication and improved quality in manufacture are being realised for residential buildings, for mixed commercial/housing projects, educational and health sector buildings.

The various design issues related to compliance with the Building Regulations, including structural action, acoustic and thermal insulation, were explored in the SCI publication: Residential Buildings using Modular Construction (SCI P302).

This publication reviews the basic principles of design using modular construction and addresses the opportunities to achieve a sensible level of standardisation, covering basic dimensions for planning interfaces with cladding, services and other details.

The main sectors of application of modular construction are:

- Private housing
- Social housing
- Apartments and mixed use buildings
- Educational sector and student residences
- Key worker accommodation and sheltered housing
- Public sector buildings, such as prisons and MoD buildings
- Health sector buildings
- Hotels



Modules supported by inclined tubular columns

KEY BENEFITS

The market characteristics that influence the choice of modular construction, are:

- Economy of scale through repetitive manufacture.
- Speed of construction.
- High level of quality control.
- Site constraints and methods of working require more off-site manufacture.
- Minimum disruption to the locality is paramount.
- Suitability for use in building renovation projects, such as roof-top extensions.

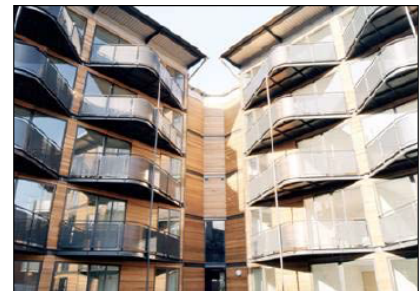


Image showing pre-fabricated balconies

Type of modules

The following types of modules may be used in the design of buildings using either fully modular construction or mixed forms of steel construction:

- 4-sided modules
- Partially open-sided modules
- Open-sided (corner supported) modules
- Modules supported by a primary structural frame
- Non-load bearing modules
- Mixed modules and planar floor cassettes
- Special stair or lift modules.

Recent applications of modular construction are illustrated.

4-sided modules

Form of construction

Modules may be designed to transfer loads continuously through their longitudinal walls. In this form of construction, modules are manufactured with four closed sides to create cellular-type spaces. The maximum width of the module that is suitable for transportation and installation limits the cellular space that is provided.

The modules are designed for the combined vertical load of the modules above and in-plane loads due to wind action. The maximum height of buildings in fully modular construction is 6 to 10 storeys, depending on location and exposure to wind loading.

Application:

Cellular buildings, such as hotels, student residences, residential buildings and key worker accommodation.

Technical details

Modules are manufactured from a series of 2D-panels, beginning with the floor cassette, to which the four wall panels and ceiling panel are attached. The walls transfer vertical loads and therefore the longitudinal walls of the upper module are designed to sit on the walls of the module below. An example of this type of module is illustrated in Figure 1.

Modules are essentially 4-sided volumetric units with openings in their ends for windows and doors. Their external width is limited by transportation requirements to approximately 4 m (3 to 3.6 m is the typical internal module width for most applications). The module length is typically 6 to 10 m.

Special lifting frames are used that allow the modules to be unhooked safely at height. Examples of lifting frames are shown in Figure 2 and 5.



Figure 1 Typical 4-sided module

The light steel walls typically use 65 to 100 mm deep C sections. The maximum height of a modular building is limited by the compression resistance of these members and also by the bracing in the walls. The floor joists are typically 150 or 200 mm deep, and the combined floor and ceiling depth is in the range of 300 to 450 mm. Details of a typical 4-sided module are illustrated in Figure 3.

Additional steel angle members may be introduced in the recessed corners of the modules for lifting and for improved stability. Module-to-module connections are usually in the form of plates that are bolted on site.



Figure 2 Module being lifted in the factory

4-sided modules

Stability

The stabilising system depends on the geometric form of the building. Various solutions are used:

- For low-rise buildings, in-plane bracing or diaphragm action of the board materials within the modules provides shear resistance, assisted by the module-to-module connections, which transfer the applied wind forces to the group of modules.
- For buildings of 6 to 10 storeys height, a vertical bracing system is often located around an access core, and assisted by horizontal bracing or diaphragm action in the corridor floor between the modules.
- For taller buildings, a primary steel podium frame may be provided on which the modules are stacked (see page 10), and supplemented by a concrete or steel core.

The maximum height of a group of modules is dependent on the stability provided under wind action. Various cases are presented in Table 1 for scheme design (based on wind loading in the Midlands of England). Details and dimensions of particular module types differ, and so precise guidance is system-specific. Taller buildings can be designed, depending on the strategy adopted for stability and fire safety.

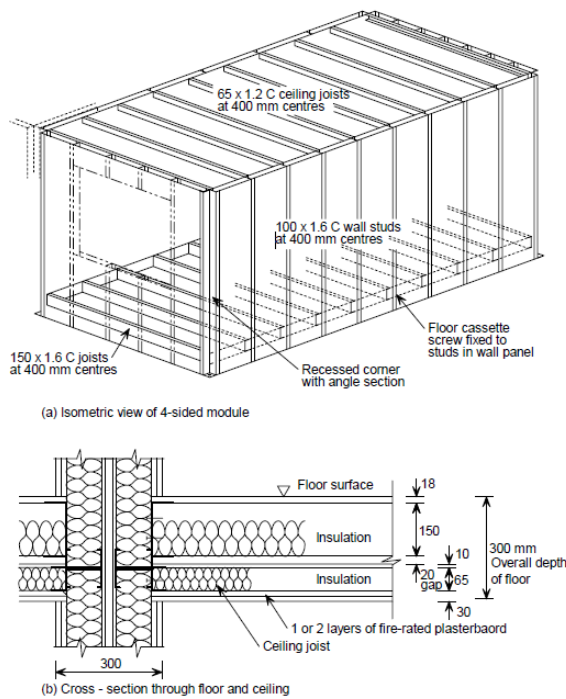
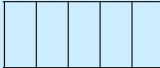
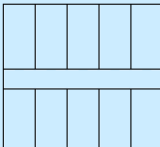


Figure 3 Details of 4-sided modules showing recessed corners with additional angle sections

All walls are insulated, and are usually boarded externally for weather protection. Additional external insulation can be attached on site.

Modules can be manufactured with integral balconies, as illustrated in Figure 4, and a range of cladding materials can be pre-attached or installed on site.

Table 1 Typical building height depending on the stabilising system using 4-sided modules

Form of Modular Construction	Bracing Requirements	Limit on size in concept design	
		Typical max. number of storeys	Min. number of modules in a group
	No additional bracing	3	5
	With additional bracing in gables	5	8
	With additional stabilising core	7	No limit
	No additional bracing	6	2 x 8
	With additional bracing in gables	8	2 x 10
	With additional stabilising core	10-12	No limit

This table is intended to give general guidance for scheme design.

Taller buildings can be designed using additional hot rolled steel members.



Figure 4 Image showing integral balconies

Partially open-sided modules

Partially open-sided modules

Form of construction

4-sided modules can be designed with partially open sides by introduction of corner and intermediate posts and by using a stiff continuous edge beam in the floor cassette. The maximum width of opening is limited by the bending resistance and stiffness of the edge member in the floor cassette. Additional intermediate posts are usually Square Hollow Sections of small cross-section, so that they can fit within the wall width.

Two modules can be placed together to create wider spaces, as shown in Figure 5. The compression resistance of the corner or internal posts controls the maximum height of the building, but 6 to 8 storeys can be achieved, as for fully modular construction. Additional edge beams are required for wider openings; the beams can be bolted to the posts. Modules can also be re-orientated at the internal posts to permit design of more flexible building forms.

Long modules can also be designed to include an integral corridor, as shown in Figure 6. This can improve the speed of construction by avoiding weather-tightness problems during installation and finishing work.



Figure 5 Partially open-ended module

Application:

Key worker accommodation, small apartments, hotels with corridors, communal areas in student residences etc.

Technical details

The form of construction is similar to that of 4-sided modules, except for the use of additional posts, generally in the form of 70 x 70 to 100 x 100 SHS members.

The edge beams in the floor cassette can be designed to span 2 to 3 m to create openings in the sides or ends of the module.



Figure 6 Long module with a corridor

Balconies or other components can be attached to the corner or internal posts. Overall stability is provided by additional bracing located in the walls of the modules. Temporary bracing for stability during lifting may be required in the open sides.

A typical building form in which larger apartments are created using partially open-sided units is shown in Figure 7 (and the completed building is shown in Figure 8). The same modular system is used for the stairs.

Use of an intermediate post to provide support to the edge beam of an open-sided module is shown in Figure 9. In this case, additional stiffening of the edge beam is required to transfer compression forces through it to the edge beam and post below.

Stability of the modules is affected by their partially open sides; additional temporary restraints may be necessary during transport and installation.

A separate bracing system may also be required, as the partially open-sided modules may not possess sufficient shear resistance in certain applications.

Partially open-sided modules may be used effectively in the renovation and extension of existing buildings to add new bathroom and balconies, as illustrated in Figure 10. The modules are designed as load-bearing, but are stabilised by attachment to the existing structure.

Partially open-sided modules

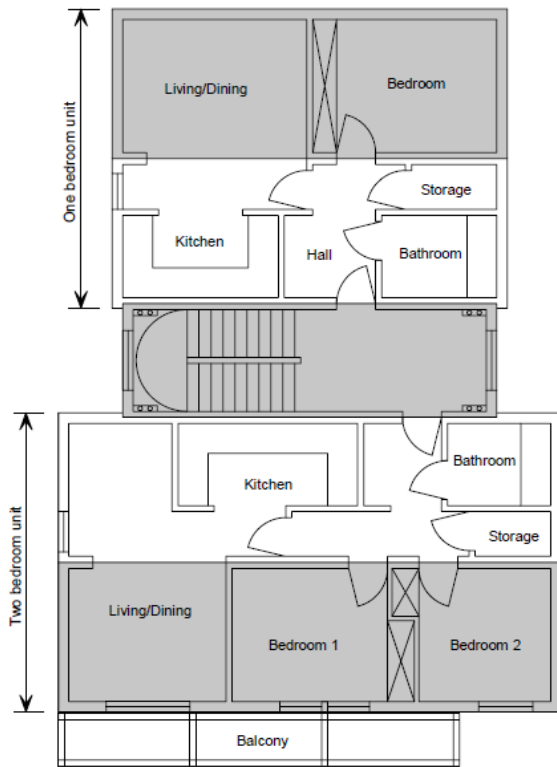
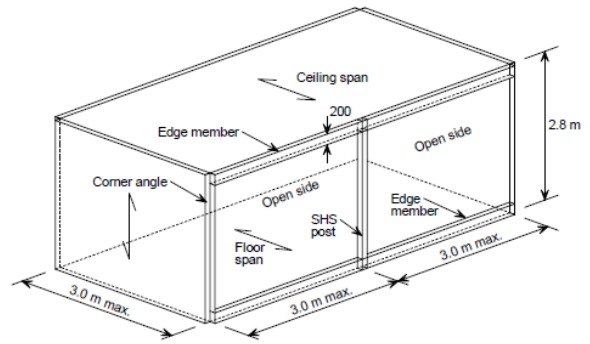


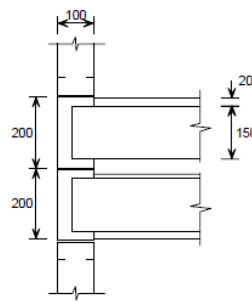
Figure 7 Layout of apartments using partially open-sided modules - alternate modules are shaded



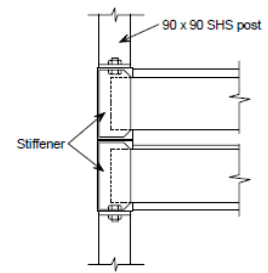
Figure 8 Completed building (above)



(a) Open-sided module using modified C section edge member and SHS post



(b) Detail on floor-ceiling showing modified C edge members



(c) Detail on SHS post with internal stiffeners

Figure 9 Use of mid-side post to provide intermediate support to the side of a module



Figure 10 Open-sided bathroom modules being attached to an existing building

Corner supported modules

Corner-supported modules

Form of construction

Modules may be designed to provide fully open sides by transfer of loads to the corner posts. This is achieved by bending of the deep longitudinal edge beams. The framework of the module is often in the form of hot rolled steel members, such as Square Hollow Section (SHS) columns and Parallel Flange Channel (PFC) edge beams, bolted together, as shown in Figure 11.

A shallower PFC section may be used to support the ceiling, but in all cases, the combined depth of the edge beams is greater than for 4-sided modules. However, modules can be placed side by side to create larger open plan spaces, as required in hospitals and schools etc.

The stability of the building generally relies on a separate bracing system in the form of X-bracing in the separating walls. For this reason, fully open-ended modules are not often used for buildings more than three storeys high. Where used, infill walls and partitions within the modules are non-load bearing, except where walls connected to the columns provide in-plane bracing. Lighter wall studs may be used.

Smaller modules up to 5.5 m length may be manufactured by re-orientating the floor and ceiling joists to run longitudinally, as in Figure 12. The joists may be of lattice form to facilitate integration of services.



Figure 11 Primary steel frame used in an open-sided module

Technical details

Open-sided modules comprise a primary steel framework and the longitudinal edge beams supporting the floor cassette. These beams are typically 300 to 450 mm deep, depending on the span, which typically is 5 to 8 m. Some systems use heavy cold formed sections, and others use hot rolled steel sections, such as PFC. The combined depth of the edge beams, the ceiling and floor can be as high as 600 to 800 mm.

Design flexibility is provided by the open-sided modules. Their width is typically 3 to 3.6 m, and rooms of 6 to 12 m width can be created by combining modules.

The corner posts provide the compression resistance and are typically use 70 x 70 to 100 x 100 SHS. The edge beams may be connected to these posts by fin plates, which provide nominal bending resistance. End plates and *Hollobolts* to the SHS may also be used. The corner posts possess sufficient compression resistance for use in buildings at least up to ten storeys, provided the bracing system is adequate.

As open-sided modules are only stable on their own for one or two storeys, additional bracing is usually introduced vertically and horizontally. In-plane forces can be transferred by the floor and ceiling cassettes and by suitable connections at the corners of the modules.

Typical details of the internal framework of an open-sided module using PFC beams and SHS posts are shown in Figures 13 and 14. Installation of open-sided modules in a hospital building is shown in Figure 15.

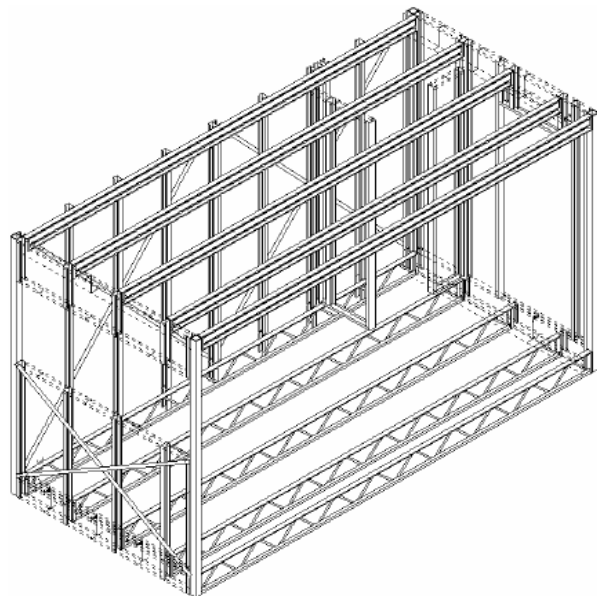


Figure 12 Smaller open-sided module using longitudinally spanning lattice joists

Corner supported modules

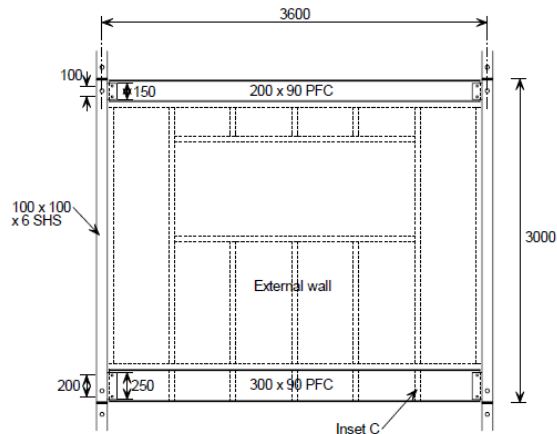


Figure 13 Structural frame of a corner supported module - end view

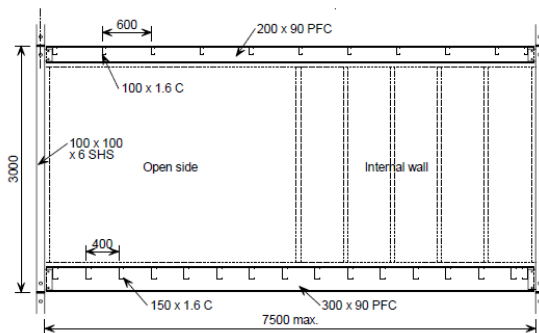


Figure 14 Longitudinal edge beams of a corner supported module



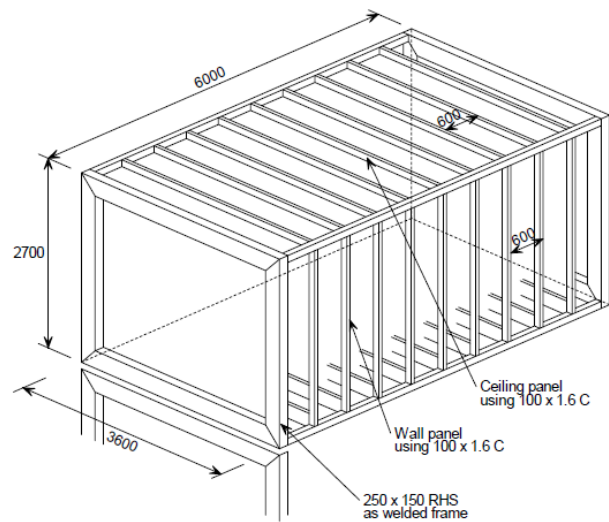
Figure 15 Modular hospital building during installation of open-sided modules

An open-ended module is a variant of a 4-sided module in which a rigid end frame is provided, usually consisting of welded or rigidly connected RHS sections. The rigid end frame provides overall stability that allows creation of a fully glazed facade, as bracing in the plane of the facade is not required.

The rigid end frame also provides attachment points of a full width cantilever balcony or walkway. A possible end frame design using 250 x 150 RHS sections welded with mitred corners is shown in Figure 16. This form of construction may be used for buildings up to six storeys.

The rigid end frames are manufactured as part of the module or can be assembled as separate components. Light steel walls may be used for the internal walls to create the required window and door openings. The module to module attachments are made on site by plates and bolts, which are tightened through holes in the RHS. The holes are capped later. The overall floor depth is typically 450 mm.

A steel 'exo-skeleton' comprising walkways or balconies may be also designed to provide stability (see page 9).



Isometric view of module and welded end frame

Figure 16 Rigid frame used to create an open end in a modular unit

Modules using hot rolled steel framework can be designed to support concrete floors for use in medical and other applications, where strict control of vibrations is required.

Mixed modular and panel construction

Mixed modules and floor cassettes

Form of Construction

In this 'hybrid' or mixed (form of construction, long modules may be stacked to form a load-bearing serviced core. Floor cassettes span between the modules and load-bearing walls, as illustrated in Figure 17. Floor cassettes may be attached to the walls of the module, usually at the corner or intermediate posts. Because of the combined depth of the floor and ceiling of the module, it is advantageous to design the floor cassettes to be relatively deep and long spanning.

The form of construction of the modules is similar to that described for open-sided modules, but the loading applied to the side of the modules is significantly higher. Therefore, this form of construction is limited to buildings of 4 to 6 storey height.

Application

Residential buildings, particularly of terraced form, comprising modular "cores" for stairs, and highly serviced areas. The modules are arranged in a "spine" through the building and the floors are attached to it - see the Corus demonstration building in Figures 17 and 18.

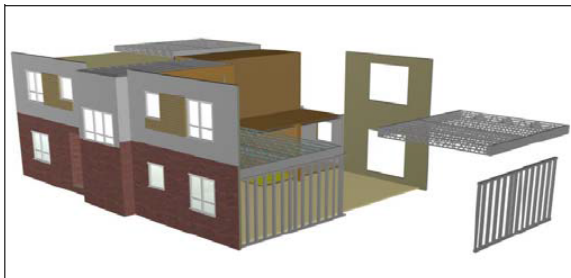


Figure 17 'Hybrid' modular and panel building showing planar floors and walls attached to the modules



Figure 18 Demonstration building system

Technical details

The modular core of a building can be designed efficiently to accommodate the highly serviced and higher value parts of the building, such as lifts, stairs, bathrooms and kitchens. This core provides the primary load-bearing and stabilising function to the whole building. Modules are usually arranged such that they occupy the full depth of buildings of terraced form.

Floor cassettes can be designed to span 4 to 6 m between the modules or load-bearing walls, and the space between the modules can be partitioned independently of the structure in order to create more flexible space. This concept was used in the design of the Corus demonstration building, shown in Figure 18.

The overall depth of the floor cassette (and the combined floor and ceiling depth of the module) is typically 300 to 450 mm. Additional SHS posts may be introduced in the modules to transfer the higher load adjacent to the open sides of the modules. The walls of the modules can be braced to provide overall stability to the building.

The facade walls can be designed as non-load bearing and can be installed as large pre-fabricated panels with their lightweight cladding attached.

A recent project in Fulham that used load-bearing bathroom modules to support the floor cassettes is illustrated in Figure 19.



Figure 19 Mixed modular and panel building using light steel framing.

Modules and primary structure

Modules supported by a primary structure

Form of construction

Modular units may be designed to be supported by a primary structure at a podium or platform level. In this case, the supporting columns are positioned at a multiple of the width of the modules (normally 2 or 3 modules). The beams are designed to support the combined loads from the modules above (normally a maximum of 4-6 storeys).

The supporting structure is designed conventionally and provides open plan space at ground floor and below ground levels. This form of construction is very suitable for mixed retail, commercial and residential developments. Modules can be set back from the facade line. An example of a mixed development in Manchester is shown in Figure 20. The ground floor and below-ground car parking is a conventional composite structure.

Alternatively, non-load bearing modules can be supported by a primary frame, and are installed as the construction proceeds. Modules can be disassembled in the future to leave the floor cassette supported by the beams.

An external steel structure, consisting of a facade structure that acts to stabilise the building, may also be used. Modules are placed internally within the braced steel 'exo-skeleton', as shown in Figure 21. The completed building is shown in Figure 37.

Application:

Podium structures, such as residential units above commercial areas or car parking etc, particularly in urban projects.

Examples of modules supported by this type of podium structure are shown in Figures 20, 22 and 23.



Figure 20 Typical podium structure in which seven storeys of residential units are supported on a composite frame below.



Figure 21 Installation of modules behind external steel framework.



Figure 22 Modular units supported by a podium.



Figure 23 Mixed use of stabilising frame and modules in a residential project.

Modules and primary structure

Technical details

4-sided modules can be designed to be supported by steel or composite beams and the typical beam line load per supported floor is 15 kN/m. Columns generally align with every 2 or 3 modules (i.e. at 6 to 10 m spacing). The depth of the podium-type structure is 800 to 1000 mm, and spans of 10 to 18 m can be created below the podium, which are suitable for commercial applications and car parking. An arrangement using cellular beams is shown in Figure 24.

The beams are designed to align with the ends of the modules i.e. at 3 to 4 m spacing, which dictates the grid of columns (i.e. at 6 to 8 m). A column grid of 7.2 m is suitable for below-ground car parking.

The podium structure is generally braced to resist wind loads and a separate braced core is often used to stabilise the group of modules above the podium level. The module design is similar to that described earlier for 4-sided modules. Wind loads can be transferred horizontally through the corridor floors.

Alternatively, the modules may also be designed to be supported by a primary steel framework at each or alternate floor level. In order to minimise the width of the modules, they should be constructed with recessed corners, which allows them to fit around smaller SHS columns, as in Figure 25.

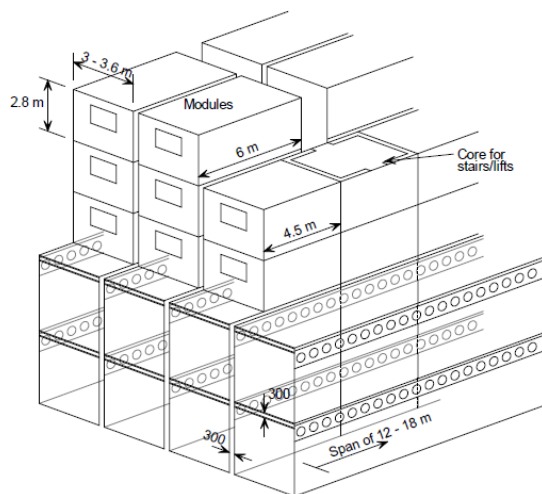


Figure 24 Modules supported by long spanning cellular beams to create open plan space at the lower levels

Applications of various types of modules with a stabilising structure are illustrated in Figures 26 and 27. The use of long-spanning floor cassettes supported on asymmetric beams is another example of 'hybrid' construction.

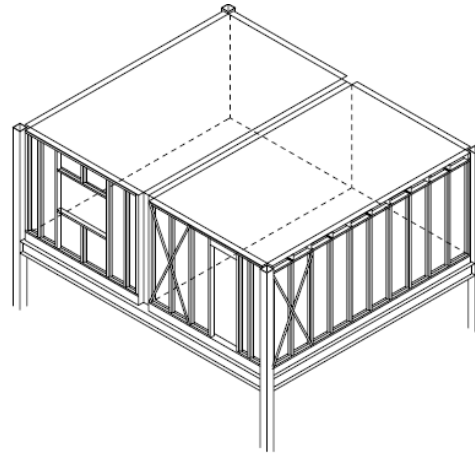


Figure 25 Recessed corner modules supported by a steel structure at each floor level

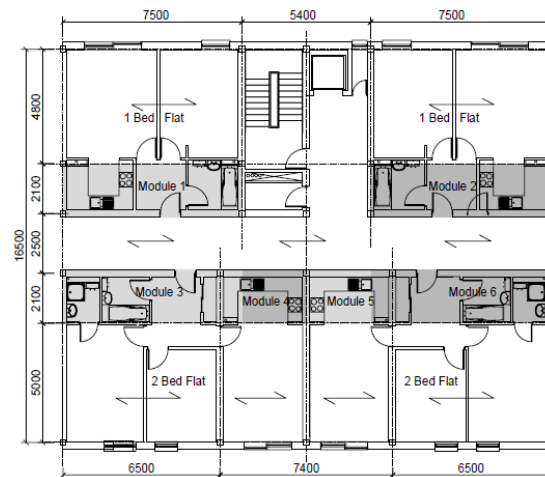


Figure 26 Mixed use of modules and long spanning floor with a primary steel frame



Figure 27 Concrete core can be used to stabilize 17 stories of modules

Other types of modules

Stair module

Form of construction

Modular stairs may be designed as fully modular units and by their nature, generally comprise landings and half landings with two flights of stairs. The landings and half landings are supported by longitudinal walls with additional angles or Square Hollow Section (SHS) members to provide local strengthening, if necessary.

Application:

Modular stairs may be used in buildings using fully modular construction up to 4 storeys in height.

Technical details

The stair modules rely for their stability on a base and top, which leads to use of a false landing. The walls may require additional strengthening members at the half and full-landing positions. The open top and base of the wall may also be strengthened by a T, L or similar members to transfer out of plane loads to the landing. The stairs can be fully or partially finished before delivery to site. SHS posts and bracing can be introduced in the walls to provide for overall stability.

Details of a typical light steel modular stair system, showing use of a 'false' landing to provide stability at the roof of the module, are shown in Figure 28.

Alternatively, be made as a the light steel the framework of the stair module may primary steel structure, in which case, walls act as infills.

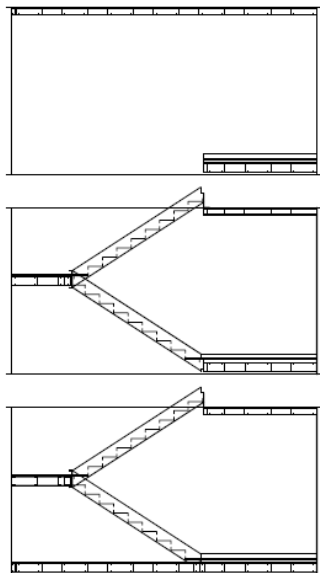


Figure 28 Detail of light steel modular stair system showing use of a 'false' landing to modules

Non-load bearing modules

Form of construction

Non-load bearing modules are of similar form to fully modular units, but are not designed to resist external loads, other than their own weight and the forces exerted during lifting. They are supported directly on a floor or by a separate structure, and are designed to be installed either as the construction proceeds or slid into place on the completed floor. The depth of the floor of the module is relatively shallow.

Application:

Toilet/bathroom units, plant rooms, other serviced units.

Technical details

The structure of the non-load bearing module (or pod) is lighter than in fully modular construction, but it must still be sufficiently rigid to resist the forces during installation. The walls and floor of these 'pods' are relatively thin (typically < 100 mm). An example of a pod used in a light steel structure is shown in Figure 29.

Compatibility of the floor depth in the module and in the floor elsewhere is achieved by one of four methods:

- Designing the depth of the floor of the module to be the same as the raised floor or acoustic layer elsewhere.
- Placing the module in a recess in the floor of the main structure.
- Designing the module without a floor (possible in small modules in which fitments are attached to the walls).
- Designing the modules to be supported on the bottom flange of *Slimflor* beams.

Modules can be slid into place on concrete floors using "air-movers" or similar systems. Bathroom modules are relatively small but the size of larger modules, such as plant rooms, is often limited by transportation.



Figure 29 Toilet 'pod' used with light steel framing

Technical Issues

Technical Issues

The following general design issues are reviewed below:

- Stability and structural integrity
- Cladding types and thermal performance
- Acoustic performance
- Balcony attachments.

Stability and structural integrity

Overall stability is provided by the modules themselves, or by an external structure. Robustness is provided by the ties between the modules; tying action when one module is notionally removed is illustrated in Figure 30. A minimum tying force equivalent to half the loaded weight of the module is normally assumed (minimum value of 30 kN).

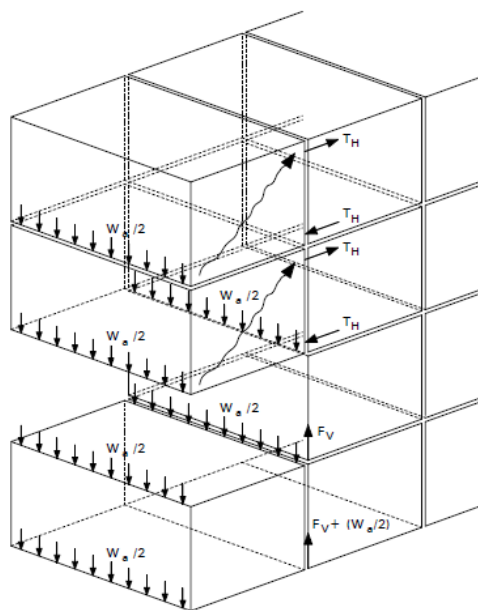


Figure 30 Tying forces in modular construction subject to loss of one module by fire or explosion

Cladding

Various forms of cladding may be used, such as:

- Brickwork, generally in-situ
- Metallic fascia
- Insulated render
- Board materials.

Typical details of various cladding systems which satisfy current thermal regulations are shown in Figures 31 to 33. Lightweight cladding can be pre-attached to the modules to eliminate the requirement for scaffolding.

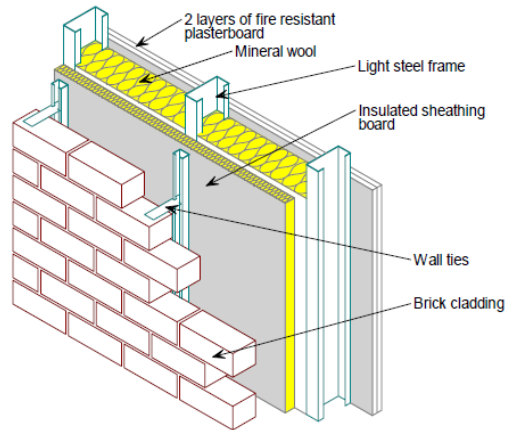


Figure 31 Brick cladding attached to light steel walls

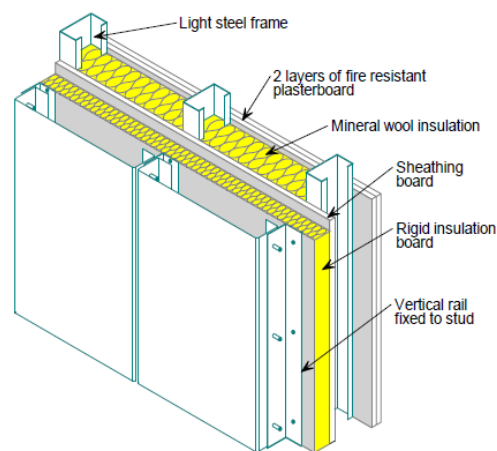


Figure 32 Metallic cassette attached to light steel walls

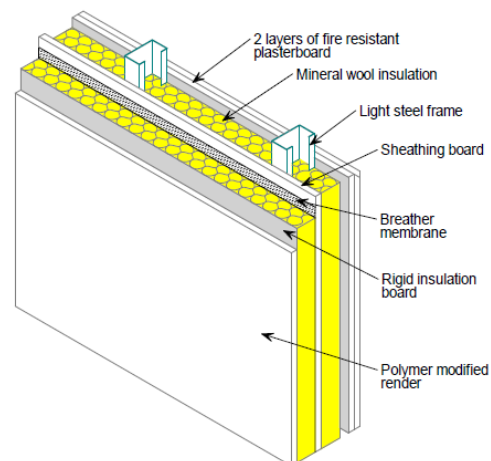


Figure 33 Insulated render cladding attached to light steel walls

Technical Issues

Acoustic performance

The double layer floor and ceiling, and pairs of separating walls, achieve excellent airborne and impact sound reductions. The off-site manufacture and quality control also ensures that all aspects of the building physics performance are more reliable. Airborne sound reductions of over 63 dB, or 52 dB (with low frequency correction factor), are achieved. These are up to 5 to 10 dB better than in Part E of the Building Regulations. Impact sound transmissions are also low (< 30 dB). In some applications, a concrete screed can be introduced, although this adds to the floor weight.

Thermal insulation

Thermal insulation is characterised by the heat loss per m² of the facade or roof (its U-value). Low U-values of 0.2 W/m²oC and excellent air-tightness can be achieved by the cladding details shown in Figures 31 to 33, meeting Part L of the Building Regulations. External insulation boards are normally placed on site.

Fire resistance

Fire resistance is provided by multiple layers of fire resisting boards (Type F to BS EN 520), assisted by mineral wool placed between the C sections. Two 15 mm thick fire resisting plasterboard layers internally plus 100 mm thick mineral wool achieves a fire resistance of 90 min. Outer sheathing boards also assist in preventing passage of smoke into the cavity between the modules. Regular cavity barriers in the form of mineral wool 'socks' in metal gauze are provided horizontally and vertically, as in Figure 34.

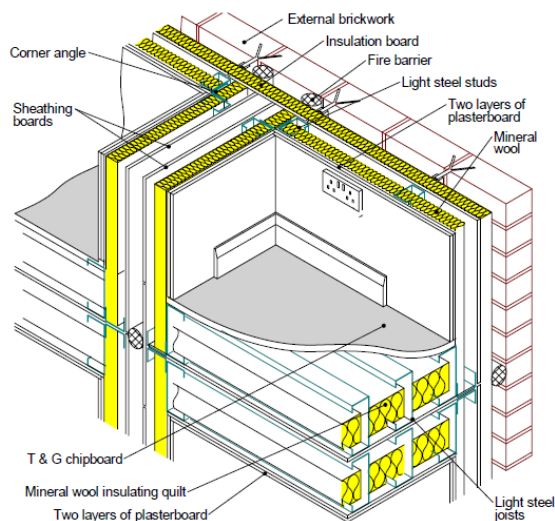


Figure 34 View of floor and wall in modular construction showing fire protection and cavity barriers

Balconies and atria

Balconies may be attached to modules in various ways:

- Balconies supported by a self-standing steel structure that is ground supported (see Figure 35).
- Balconies attached between adjacent modules.
- Balconies that are attached to corner posts in the modules (see Figure 36).
- Integrated balconies within an open sided module, as was used in the Raines Court project (see Figure 4).

An atrium may be created by spanning the roof between the modules as shown in Figure 37.



Figure 35 Self-standing balcony.

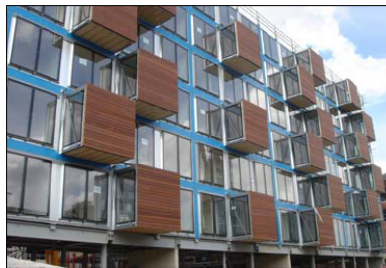


Figure 36 Balcony attachments to external structure.



Figure 37 Atrium created between modules.

Dimensional Planning

Dimensional planning

The factors that influence the dimensional planning of modular systems in general building design may be summarised as:

- Cladding requirements, including alignment with external dimensions of cladding
- Planning grid for internal fit-out, such as kitchens
- Transportation requirements, including access
- Building form, as influenced by its functionality
- Repeatability in modular manufacture.

Cladding

Brickwork design is based on a standard unit of 225 mm width and 75 mm depth. Therefore, it may be important to design a floor-floor depth to a multiple of 75 mm in order to avoid non-standard coursing of bricks. The multiple of 225 mm in horizontal brickwork coursing width is more difficult to achieve in terms of the module width and the window size. At corners and brickwork returns, a variable width cavity may be detailed.

Other types of cladding, such as clay tiles or metallic finishes, have their own dimensional requirements, but generally they can be designed and manufactured to fit with window dimensions etc. Many types of lightweight cladding can be pre-attached to the modules, but it is generally necessary to install a cover piece over the joints between the modules on site, to cater for geometrical tolerances and misalignments.

Standardisation of planning grid

Standardisation of the planning grid is important at the scheme design stage, as the planning grid will be controlled mainly by other building components and fitments. A dimensional unit of 300 mm may be adopted as standard for vertical and horizontal dimensions, reducing to 150 mm as a second level for vertical dimensions, i.e. a multiple of either 2 or 4 bricks. Typical dimensions for planning in modular construction are presented in Table 2. Typical wall and floor dimensions are illustrated in Figure 38, although actual dimensions are system-specific. For planning, a combined wall width of 300 mm may be used.

External walls are detailed according to the type of cladding. Again, a 300 mm total wall width may be adopted as a guide for most cladding materials. The actual width will vary between 200 mm for insulated render and board materials to 320 mm for brickwork.

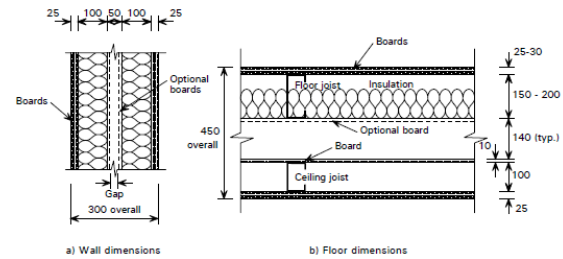


Figure 38 Typical wall and floor/ceiling dimensions

Transportation

Guidance on transportation on major roads is given by the Road Haulage Association, based on the Road Vehicles (Construction and Use) Regulations.

The following basic requirements for transportation should be considered when designing the sizes of modular units:

- Modules exceeding 2.9 m external width require 2 days notice to the police.
- Modules exceeding 3.5 m width require a driver's mate and 2 days notice to the police
- Modules exceeding 4.3 m width require additional speed restrictions and may require police escort.

Stricter limits may be required for local roads, particularly in urban areas. In all cases, the maximum height of the load is 4.95 m for motorway bridges. Standard container vehicles are typically 6.2 m or 12.2 m long, and can deliver one large or two smaller units.

Internal walls

Internal walls may be designed for a standard 300 mm face-face overall width, incorporating the various boards and insulation. The gap between the walls is a variable, depending on the number and thickness of boards and size of the wall studs. In practice, most modular systems lead to total wall widths in the range of 250 - 300 mm.

Table 2 Typical dimensions for planning in modular construction

Application	Internal wall height mm	Internal module width mm	Internal module length m	Ceiling-floor zone (typical) mm
Study bedrooms	2400	2500-2700	5.4 to 6	300
Apartments	2400	3300-3600	6 to 9	450
Hotels	2400-2700	3300-3600	5.4 to 7.5	450
Schools	2700-3000	3000-3600 open-sided	9 to 12	600
Offices	2700-3000	3000-3600	6 to 12	600-750
Health sector	2700-3000	3000-3600 open-sided	9 to 12	600-750

Dimensional Planning

Floor zone

Floors and ceilings in modular construction are deeper than in more traditional construction. The three structural cases noted earlier will require different overall ceiling-floor dimensions for planning purposes, as follows:

- Continuously supported modules 300 or 450 mm
- Corner supported modules 450 to 600 mm
- Frame supported modules 750 to 900 mm

In most cases, 450 mm may be adopted as a standard for the floor-ceiling dimension, although many systems provide shallower depths. A floor and ceiling zone of 300 or 375 mm is feasible in some systems and aligns with brick coursing.

The details of a corner supported module are illustrated in Figure 39. In most cases, a standard overall floor and ceiling depth of 600 mm may be used. The gap between the floor and ceiling is a variable depending on the number of boards and the joist size.

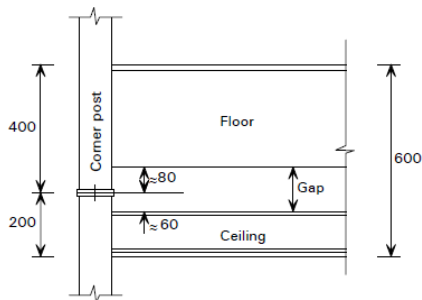


Figure 39 Detail of corner supported module

Actual dimensions of the modules will be less than these planning dimensions to allow for gaps (by up to 50 mm for walls, and up to 150 mm for floors). Windows and doors may also be incorporated as standard dimensions to achieve a variety of opening configurations, as illustrated in Figure 40.



Figure 40 Window configurations in modular units

Attachment points

Generic forms of attachment using angles at the corners of modules are presented in Figure 41.

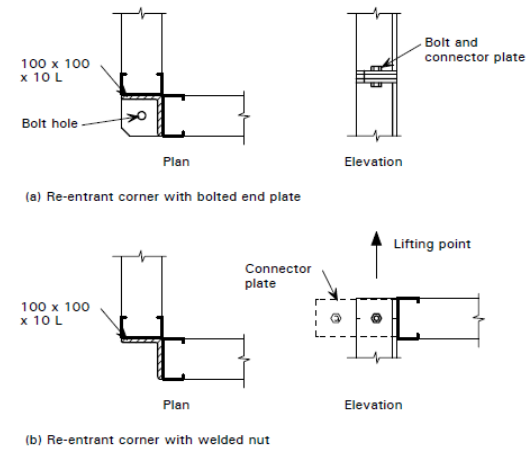


Figure 41 Corner posts using hot rolled steel angles

SHS provide the highest compressive resistance and may be used as the corner posts for open-sided modules. However, although these sections are compact, their connections can be more complex. Figure 42 shows a welded fin plate to which the edge beams are bolted. Access holes of 50 mm minimum diameter in the SHS allow bolts to be inserted through end plates to provide for vertical and horizontal attachments.

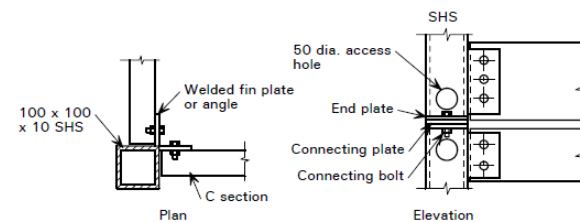


Figure 42 Corner post using SHS or special sections

Attachments between modules are made in both horizontal and vertical directions, primarily to transfer in-plane forces, but also for structured integrity.

Services

Services are usually pre-installed within the module and service attachments are made externally to the modules, usually in the corridor zone. The ceiling zone of the corridor provides for longitudinal service distribution. The modules can be constructed with a recessed corner zone for vertical service routing, or a separate service zone may be constructed outside the module.