Renovation of Buildings using Steel Technologies (ROBUST)

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WP 3.1
Review of modular construction in building renovation

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APPLICATION OF MODULAR CONSTRUCTION IN BUILDING RENOVATION

1. INTRODUCTION

There is an important social and economic argument for renovating multi-storey concrete and masonry buildings of the 1950's and 1960's. It is estimated that over 20,000 high-rise buildings were constructed across the EU between 1950 and 1970. Many of these are in need of urgent attention, ranging from demolition to repair and renovation. Modular construction consists of factory produced volumetric units that are widely used for single person accommodation and social housing. Modular construction possesses many advantages in terms of renovation:

- New facilities are added cost-effectively.
- Construction is rapid, which minimises costs and disruption.
- High quality can be achieved by off-site manufacture.
- Delivery of modules can be timed to suit local conditions.
- The light weight of the modules does not over-load the existing building.
- In some projects, it is not necessary for the occupants to move out during the renovation work.
- The external appearance of the building is dramatically improved.
- The life of the existing building is increased (because its deterioration is reduced).

Often, new modular units are used as part of an over-cladding or re-façading process in which the thermal insulation of the existing facade is improved greatly in order to reduce the overall energy use of the building.

The opportunities for modular construction as part of a comprehensive refurbishment of these buildings are as follows:

- Extensions to buildings to provide new toilet and bathroom units and service risers.
- Enclosing existing open balconies to provide better internal environments.
- New enclosed stairs and access walkways (or replacement of existing stairs).
- New balconies and other features.
- New external lifts.
- Roof top extensions to create new apartments or communal space.
- Conversion of redundant office buildings into apartments.

The economics of these major renovation projects are such that they should "pay-back" over 20 to 30 years in terms of:

- Reduced heating bills (due to higher insulation levels).
- Increased rental charges (due to better quality environment and habitable space).
- Additional sales revenue, such as from new roof-top apartments.
- Less maintenance of the existing building fabric.

Technical issues

A particular application is in the attachment of external modular units to concrete or masonry buildings. The modular units form part of the remodelling of the building façade and reduce the weathering or deterioration of the existing structure. The technical issues that are appropriate to the use of modular units in this sector are as follows:

- The buildings are often tall (10-20 storeys) and the modular units are stacked on top of each other. The lower units should therefore be strengthened in order to avoid over-engineering of the modular units at higher levels.
- Overall stability is provided by attachment to the original structure. Therefore, 'strong points' should be identified on the existing floors or columns to avoid instability of the stack of modular units.
- The cladding to the modular units should be compatible with the cladding to the rest of the building.
- Lightweight facade materials may need to be attached by sub-frames to the modular units and also to the existing building.
- Modular units used in roof-top extensions should be supported on load- bearing walls. Care must be taken not to overload the existing structure.
- The foundations to the external modular units should be sufficient to avoid differential settlement problems with the existing structure.

The rationale for the use of modular construction in renovation is often determined by avoidance of disruption to the occupants, who are usually not moved out during the renovation process. The economics of modular construction improve considerably if a number of similar blocks are renovated in the same fashion.

Over-cladding may also be considered as part of a comprehensive renovation to improve the thermal performance of the building.

Modular toilet and bathroom units

Highly serviced toilet and bathroom units may be stacked externally to the building and accessed either through the existing facade or by the covered former walkways that are now part of the habitable space. Installation of a modular toilet unit at a project in Forssa, Finland is shown in Figure 1. The units were clad with steel cassette panels, which were insulated behind with 150 mm thick mineral wool.

Figure 1 *Installation of modular toilet units*
(courtesy Ruukki)

The box-like appearance of the original concrete panel structure was transformed by these modular units with new galvanised steel balconies spanning between them. The building was over-clad using concrete panels, as shown in Figure 3.

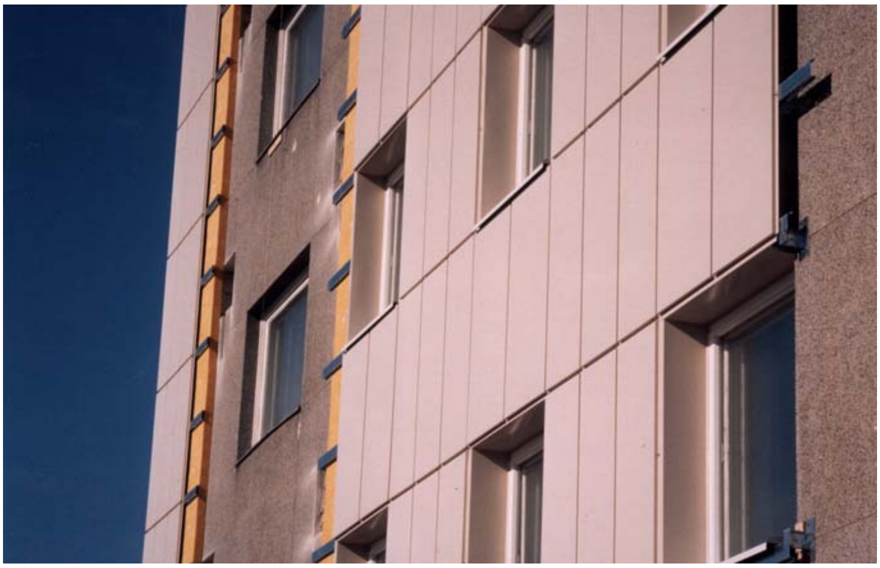


Figure 2 *Over-clad building using cassette panels*
(courtesy Ruukki)

Modular roof-top extensions

Modular roof units may be prefabricated and lifted into place, provided the crane has sufficient height and capacity. It is apparent that this technique is most appropriate for low- and medium-rise buildings. Units are designed to span between load-bearing walls, usually internal cross-walls. The flooring elements and cross-beams need to be sufficiently rigid to allow them to span between the cross-walls.

Modular stairs, lifts and balconies

New balconies, external stairs and lifts and disabled access can be provided by modular components. An example use of this technology was in the renovation of a concrete tower block to provide new facilities and to improve the thermal insulation and appearance of the building. New balconies and external lifts were installed, as shown in Figure 3.

Figure 3 *New balconies and over-cladding as part of the restoration of a 1960s tower block*

2. USES OF MODULAR UNITS IN RENOVATION

The use of modular units in building extensions and renovation depends on the scale of the project, the quality of the existing buildings, and the new facilities that are required. Four well-defined cases are presented below:

New modules attached to the elevation of a building

The modules are stacked vertically and are supported on new foundations. They are tied laterally into the existing structure for stability, but otherwise exert no significant force on it. The maximum height of the group of modules depends on their structural design but essentially 4 to 8 storeys are feasible. Modules may be placed on two, three or four sides, as illustrated in Figure 4.

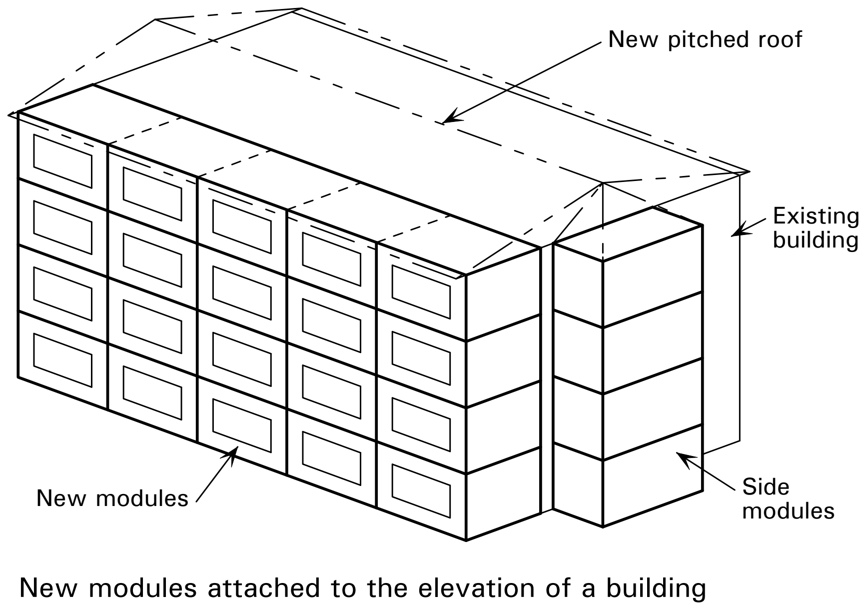


Figure 4 *Modules stacked to the side of an existing building*

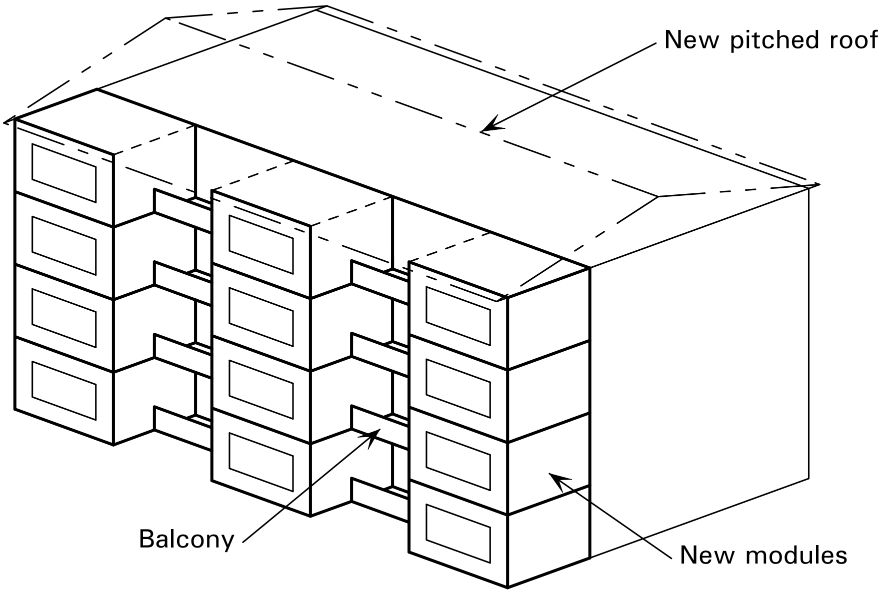
Access from the existing building to these modules is often created by forming doors in the existing windows. The new modules may comprise bathrooms, kitchens and other facilities.

Often a new roof is added to the renovated building, primarily to conceal and waterproof the interface between the new modules and existing building.

New modules and balconies

This case is a practical adaptation of the previous example, in which new modules extend the building at certain locations and new balconies (often enclosed) span between the modules. In this way, the architectural impact is much improved and high quality space is created. Figure 5 shows a representation of this form of construction, although many alternative solutions are possible.

The balconies are attached to the side of the modules and are independent of the existing building. Again, a new roof is often added.

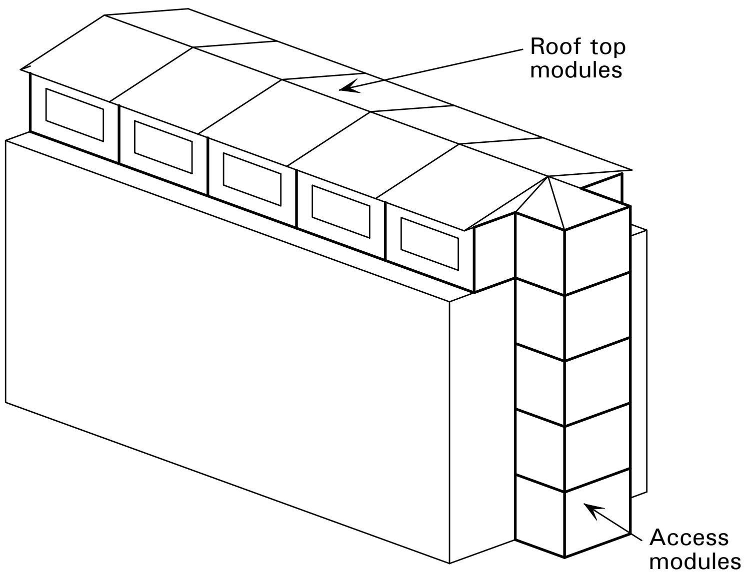


Mixed use of new modules and balconies

Figure 5 *Mixed use of new modules and balconies*

Roof-top extensions using modules

Large modules may be added to an existing flat roof to create high quality penthouse apartments. In this case, the use of lightweight modular construction minimises the loads on the existing roof. Separate modules are often required at the edge of the building for access, independent of the rest of the building. Figure 6 shows a representation of this form of construction.



Roof top modules with separate access

Figure 6 *Roof-top modules and access modules*

Comprehensive renovation

There is often an opportunity in major renovation projects to reconfigure the whole building using many of the techniques described above. Figure 7 shows such a project in which most of the existing facade and roof is extended. The remaining part is often over-clad to create the desired appearance.

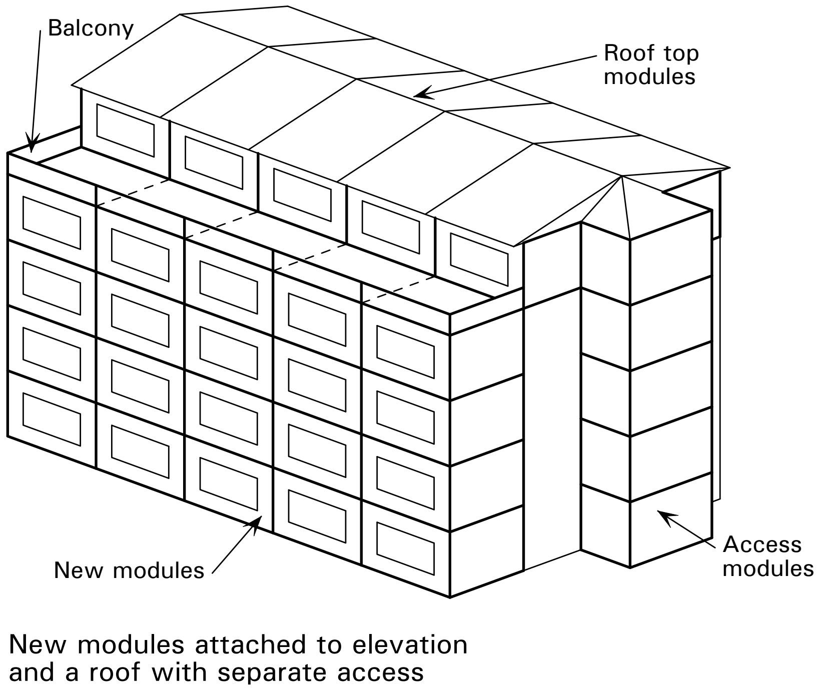


Figure 7 *New roof-top and side modules*

In this form of construction, the whole building façade can be remodelled. Separate access is often required to the roof-top modules, which can be provided at the side or ends of the building, as shown above.

3. CASE STUDIES

A number of potential renovation projects were identified, in order to demonstrate how these buildings might be renovated using modular construction and provide a good insight into practical issues that may be encountered. The projects are as follows:

1.	Copenhagen, Denmark	Roof-top extension and over-cladding of 1960s social housing
2.	Edinburgh University	Renovation of 1960's student residence
3.	Tower Hamlets Housing Association, East London	Renovation of 1930's social housing
4.	Hämeenlinna, Finland	Roof-top extension of 1970's concrete apartment building
5.	Plymouth University	Roof-top extension of 1948 office building

They are presented in order, describing the proposed renovation plans.

Copenhagen, Denmark

In a project in a suburb of Copenhagen, one 8-storey and two 4-storey apartment blocks were renovated using colour-coated steel wall panels and modular placed units placed on the roof to create new communal space. One of the roof-top units being lifted into place is shown in Figure 8. The building's appearance was further enhanced by use of steel tubular members to support the cantilevered roof and to protect the walkway around the new roof units. The completed building is shown in **Figure 9**.

The units were supported on three cross-beams that were supported on steel columns over the existing concrete walls. The roof construction used stainless steel sheets on plywood and insulation. A cross-section through the new roof construction is shown in Figure 10.

Figure 8 *Erection of modular units in roof-top extension in Copenhagen*

Figure 9 *Completed renovated building in Copenhagen*

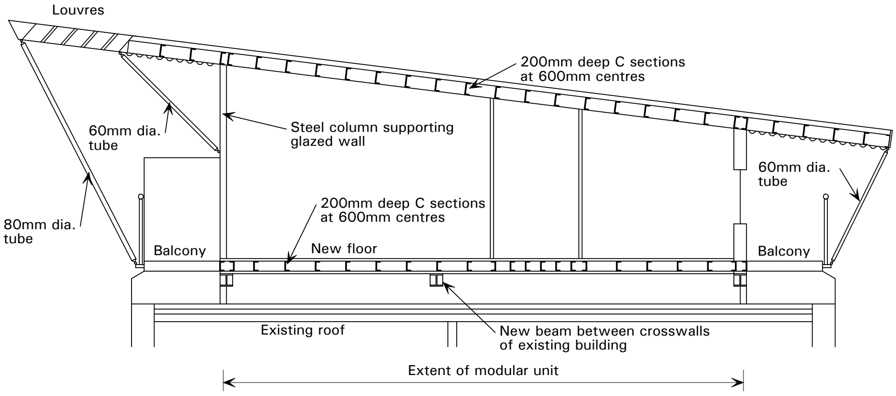


Figure 10 *Cross-section through over-roofing scheme in Copenhagen*

Edinburgh University

The University of Edinburgh built a series of 3 storey student residences in the late 1960's which were also used as accommodation for the 1972 Commonwealth Games. The University wished to provide new facilities for conferences and possibly to extend the buildings to provide new accommodation. The building structure consists of concrete slabs on masonry cross-walls.

Three proposals for renovation were considered:

- New external toilet/bathroom modules.
- New internal toilet/bathrooms with external walkways.
- Roof-top modules with combinations of the above options.

The University Department of Architecture was commissioned to carry out visualisations of the proposed schemes. Each building is approximately 20 m long and 10 m wide with cross-walls at 3 m spacing. The corridors are only 0.9 m wide. The elevation consists of wide concrete panels with vertically-orientated windows. The original building form is shown in Figure 11.

The various renovation options were addressed as follows:

- New external modules

  The external toilet/shower modules are arranged in pairs and occupy half of the façade. New full-height double glazed windows are installed between the modules to allow for sufficient light. A variety of lightweight façade materials were considered.

- New internal modules and external walkways

  New toilet/shower modules are installed in the existing corridor space to service opposite bedrooms. Access to the rooms is achieved by new stair modules and access walkways supported by new columns. The walkways are enclosed for weather protection. This scheme is illustrated in Figure 12.

- New roof-top modules and external stairs

  Room-sized modules may be placed on the existing roof and supported by the cross-walls. Independent access is provided by new external stairs. The roof-top extension may be combined with either of the previous options in a comprehensive renovation. This scheme, with new external modules, is illustrated in Figure 13.

The schemes were presented to the University, together with a value-assessment of the major renovation options, based on increased rental income and reduced maintenance.

Figure 11 *Elevation of existing building at Edinburgh University*

Figure 12 *Visualisation of external modules and roof-top modules*

Figure 13 *Visualisation of external stair modules*

Tower Hamlets Housing Association, East London

A series of 1950's concrete buildings in the Minerva Estate of Tower Hamlets, East London was planned to be renovated. Architects HTA Associates, acting for the Housing Association, proposed a scheme which consisted of:

- External toilet and bathroom modules.
- Balconies spanning between the modules.
- Stair and loft modules.
- Roof-top apartment modules.

The toilet and bathroom modules are intended to be supported by the existing concrete balconies and the lift/stair modules will connect to pairs of apartments of each level. The complete building used over-clad to a consistent style.

The new roof-top apartment will form single or double bedroom apartments around a central corridor, with access via new stairs and lifts. The structure of the existing building was checked for its ability to support the new loads, and the new roof-top modules would prevent deterioration and rain ingress in the existing roof.

A visualisation of the renovated 4 storey building is illustrated in Figure 14. Large cassette panels are attached to the façade and to the modules to create a consistent appearance of the façade and roof-top extension.

Figure 14 *Visualisation of new modules and over-clad façade at the Tower Hamlets*

Hämeenlinna, Finland

The buildings are situated in Hämeenlinna, in the middle of a suburban area and were constructed in 1976–78. The owner of these buildings, Hämeenlinnan Seudun Opiskelija-asuntosäätiö, a specialist provider of student accommodation decided that the buildings should be renovated in order to fulfil better the needs of modern students.

The original three-storey high buildings consist of an on-site cast concrete wall and floor frame and pre-cast concrete sandwich element wall panels, as shown in Figure 15. The load bearing capacity of the existing frame was calculated to support the extra weight of the new steel frame for the fourth floor apartments. It was planned to construct 5 new single bedroom and 3 two bedroom apartments consisting of 11 modules on the roof of the first building and 12 identical one bedroom modules on top of the second building.

The main contractor for the project was Rakennustoimisto A.Palmberg Oy. The construction was carried out simultaneously both inside and outside of buildings, starting from assembly of balcony-type steel staircase and continuing to the elevator shaft and balconies.

The various modular components are illustrated in Figure 16. The demonstration building under construction is shown in Figure 17, which identifies the new structure and lightweight walls. Due to the development phase of the building system, the additional floors were assembled on site from separate components consisting of a tubular steel frame, pre-fabricated large panel wall elements, steel roof trusses and floor structures. The floor structures were also assembled on site.

The construction programme is shown in Figure 18, which defines the construction and installation of the steel component modules as part of the overall programme. The total construction time in first building was only 6 months. The completed building is shown in Figure 19.

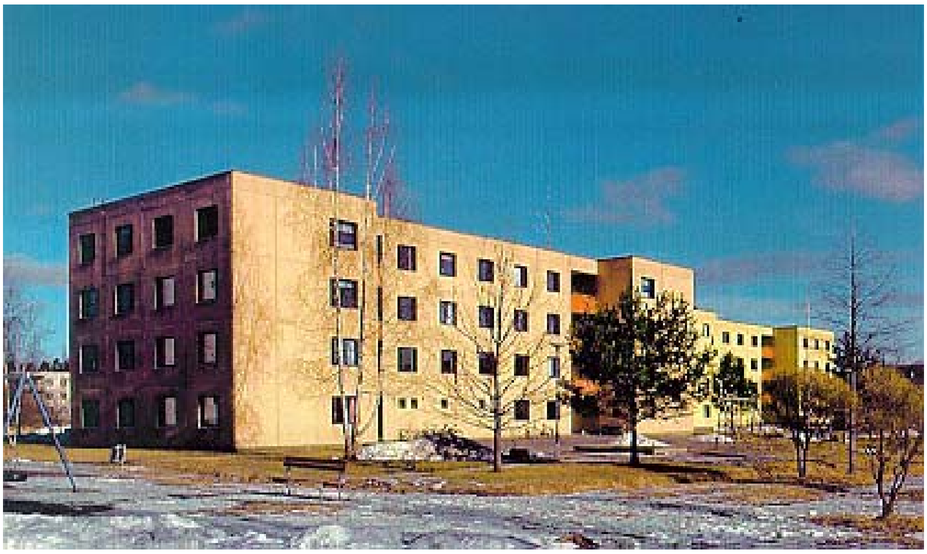


Figure 15 *Demonstration buildings in Hämeenlinna before renovation*

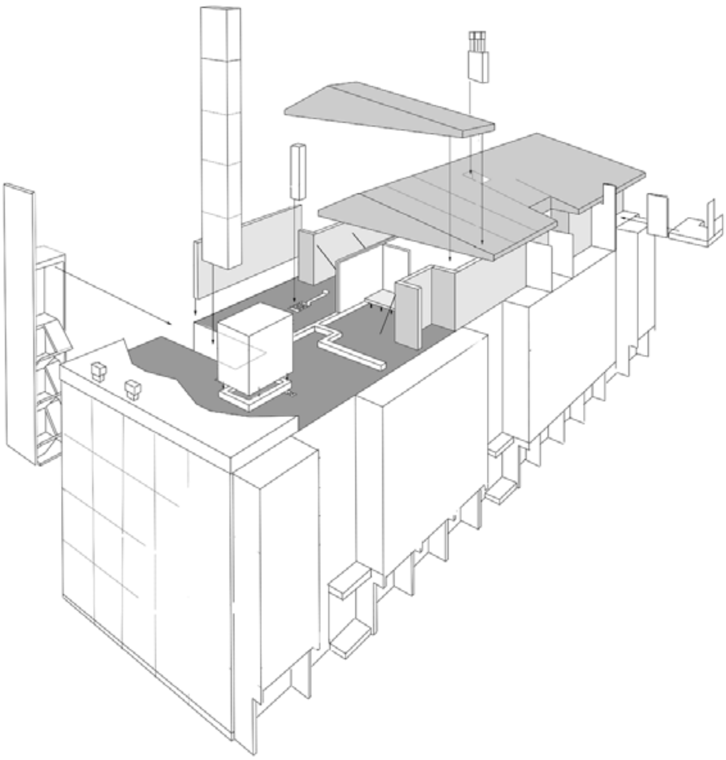


Figure 16 *Modular components for renovation. Staircase, elevator shaft, bathroom module, load bearing light wall panels, roofing modules and balconies.*

Figure 17 *Demonstration building under construction in Hämeenlinna*

	Month									
Activity	1	2	3	4	5	6	7	8	9	10
Demolition work	xxxx	xxxx								
Staircase			xx	xx xx	xx					
Balconies				xx	xx					
Elevetor shaft					xx	xx				
Fourth fourth floor				xxxxx	xx xx	xxxx				
Complementary activities										
Completion of the project										o

Figure 18 *Construction and renovation programme*

Figure 19 *Completed renovated building in Hämeenlinna*

University of Plymouth

The educational sector is expanding in the UK, as Universities seek to attract students, and to improve their existing building stock. A project was identified in Plymouth, which involved extending an existing 4-storey building vertically to create new student bedrooms. Modular construction was the only practical solution for this project because of the limited access to the building, and the tight construction programme (less than 6 months). The building is on the campus of the University of Plymouth, and the University was also asked to take part in the pre-construction trials and the in-service performance monitoring.

The building consists of a steel frame with concrete slabs and was constructed in 1948. It was planned to install 28 modules on the roof, together with communal areas in light steel framing. The remaining part of the building was to be renovated using light steel wall panels.

The existing roof was not considered to be strong enough, nor sufficiently weather tight, and so a grillage of steel beams was first installed on the roof and supported on the existing columns. The grillage was located at the edges of the modules, and was designed to support the modules and roof.

The modules were designed and manufactured by Corus Framing and are fitted out by Unite in Bristol. The modules are 5.1 m long and 2.4 m wide, and are constructed using 75 mm deep × 1.6 mm thick C section wall studs and 225 mm deep lattice joists. Square hollow sections were introduced at the corners so that the windows could extend over the module width, and could provide sufficient wind resistance.

The modules were constructed with one open side so that adjacent modules could be placed together to minimize the internal wall thickness and meet the tight internal planning requirements. The walls used 2 layers of *Fermacell* board for rigidity and sound insulation. Figure 20 shows the structural components in the module.

Each module weighed 2.5 tonnes when fully fitted out. Pre-construction trials demonstrated the robustness of the modules to lifting and transportation. Modules were delivered to site in January and installed over a 4-day period, allowing for 2 days that were lost due to severe wind conditions. Figure 21 shows a module being lifted into place.

The communal areas were constructed using light steel framing, using pre-fabricated wall panels. Roofing was also pre-fabricated in panel form. Light weight over-cladding panels were attached to the modules.

The construction programme is shown in Figure 22, which defines the construction and installation of the modules as part of the overall programme. The estimated time saving relative to site construction was 3 months. The completed building is shown in Figure 23.

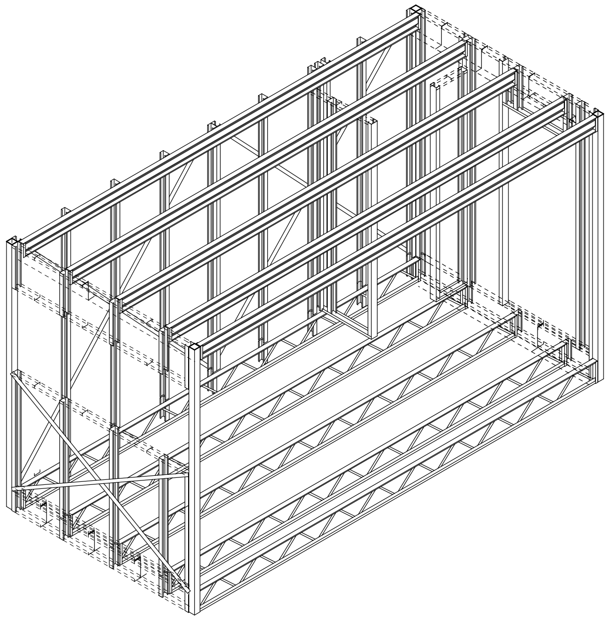


Figure 20 *Structural components of open-sided modules*

Figure 21 *Module being lifted into place at Plymouth University*

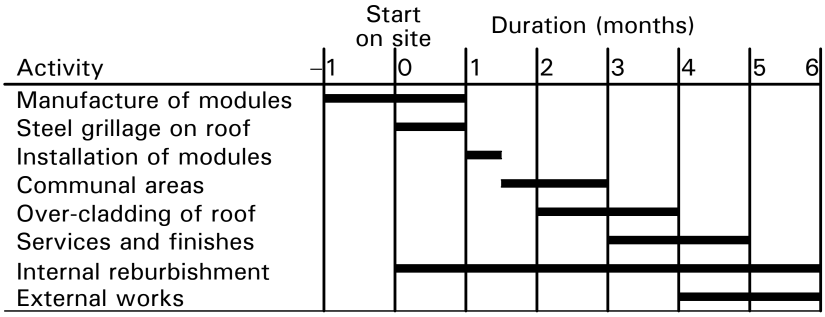


Figure 22 *Construction programme for modular installation*

Figure 23 *View of completed roof-top extension*

For acoustic performance, each side of the separating wall between modules consisted of two layers of 12.5 mm thick plasterboard with staggered taped joints fixed to the light steel studs. Cavities between studs were filled with 60 mm thick mineral fibre batts and each wall frame was externally faced with 4mm MDF boards. Room modules were positioned such that there was a 30 mm gap between the faces of the boards.

The separating floor was constructed with 100mm mineral fibre between the floor joists and 35 mm thick foam insulation board below the floor. The estimated mass of the separating floor was 66 kg/m^2.

The results of the tests were as presented in the following table:

Table 1 *Measured acoustic insulation provided by the modules*

	Airborne (DnT,w)	**Impact (L'nT,w)**
Wall	57	
Floor	63	55

The UK Building Regulations require that walls should achieve a $D_{nT,w}$ of at least 49 dB and that the mean result from up to four sets of tests should be at least 53 dB. The airborne sound insulation result for walls, and the airborne and impact sound insulation results for floors therefore satisfies the performance requirements.

Further tests were carried out for a 'heel drop' - that is the raising and sudden dropping of the heels of a person of 80 kg weight onto the floor. This impact is relatively severe in terms of normal daily activities, but gives a good measure of the likely vibration response of the floor.

Measurements were taken in bedrooms midway between supporting beams in the grillage below. Therefore, the response would be that of the floor and the grillage. The natural frequency was measured as between 12 and 16 Hz, and the damping was approximately 5%. The highest root mean square RMS acceleration measured due to 'heel drop' was 0.36 m/s^2, which leads to a response factor of approximately 36 for this impact loading relative to the base perceptibility of BS 6472 (at 16 Hz). It is considered that this is reasonable for everyday activities, indeed, the user reaction to the new accommodation has been good.

Future Opportunities

There are opportunities to develop specific modular steel technologies aimed at the renovation sector, including:

- Mansard-shaped modules for roof top extensions, of the form illustrated in Figure 24
- Balcony systems, either ground-supported or cantilever balconies that can be fully enclosed, as shown in Figure 25
- Load-bearing modules that support infill balconies, as shown in Figure 26. In this case, a completely new façade and building profile is created
- Integrated façade materials and other features

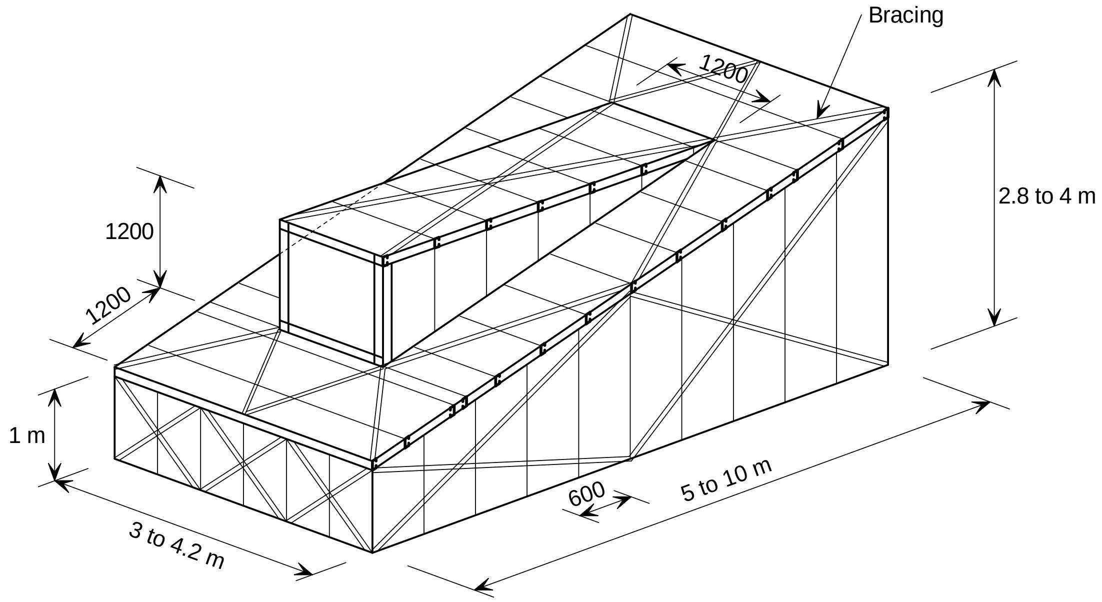


Figure 24 *Mansard module in light steel framing*

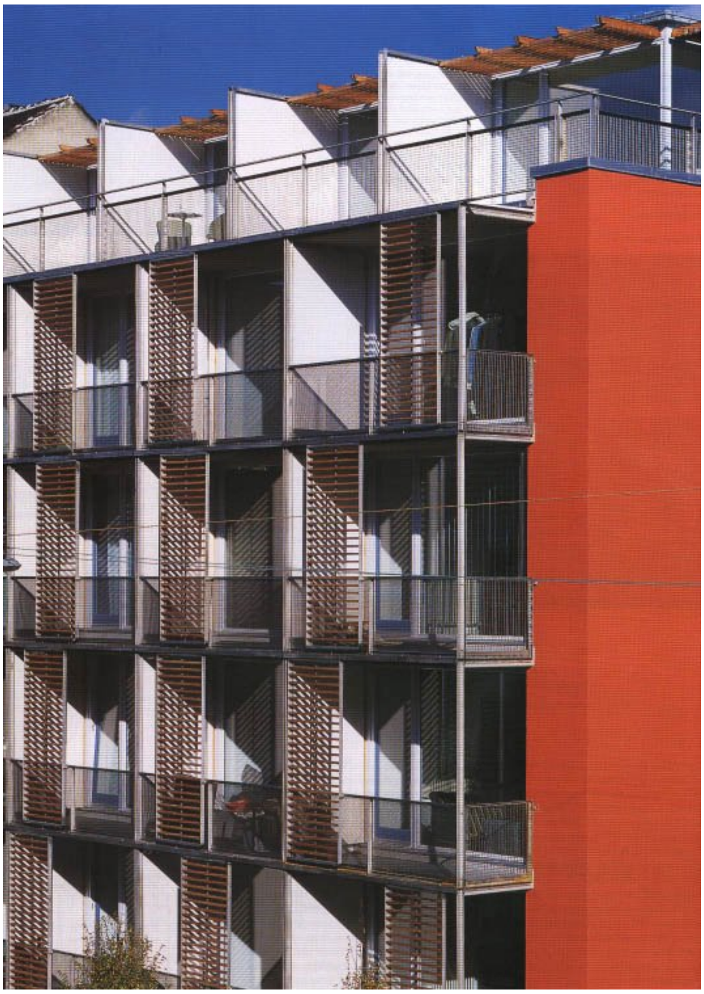


Figure 25 *Balcony system installed as a module*

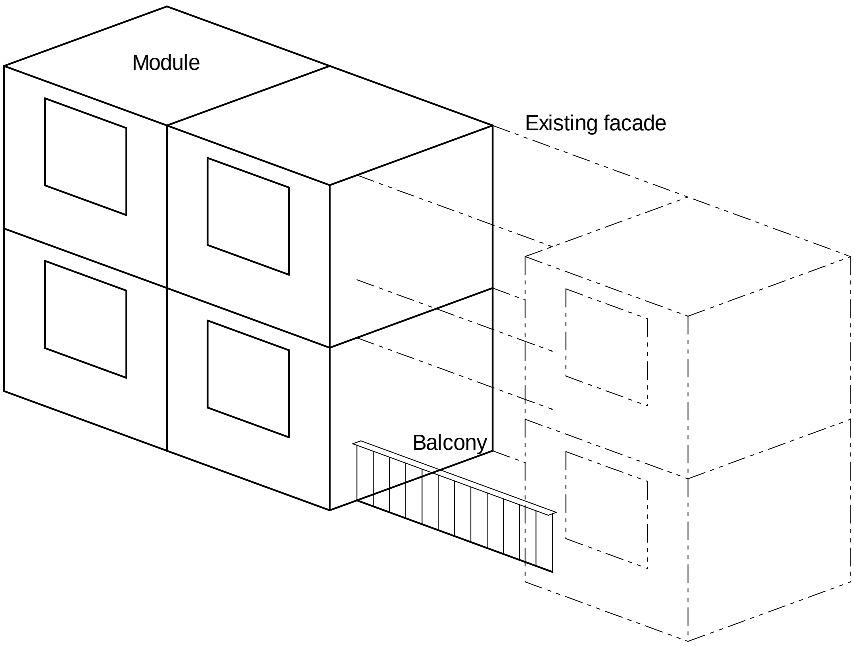


Figure 26 *Balcony system installed as a module*