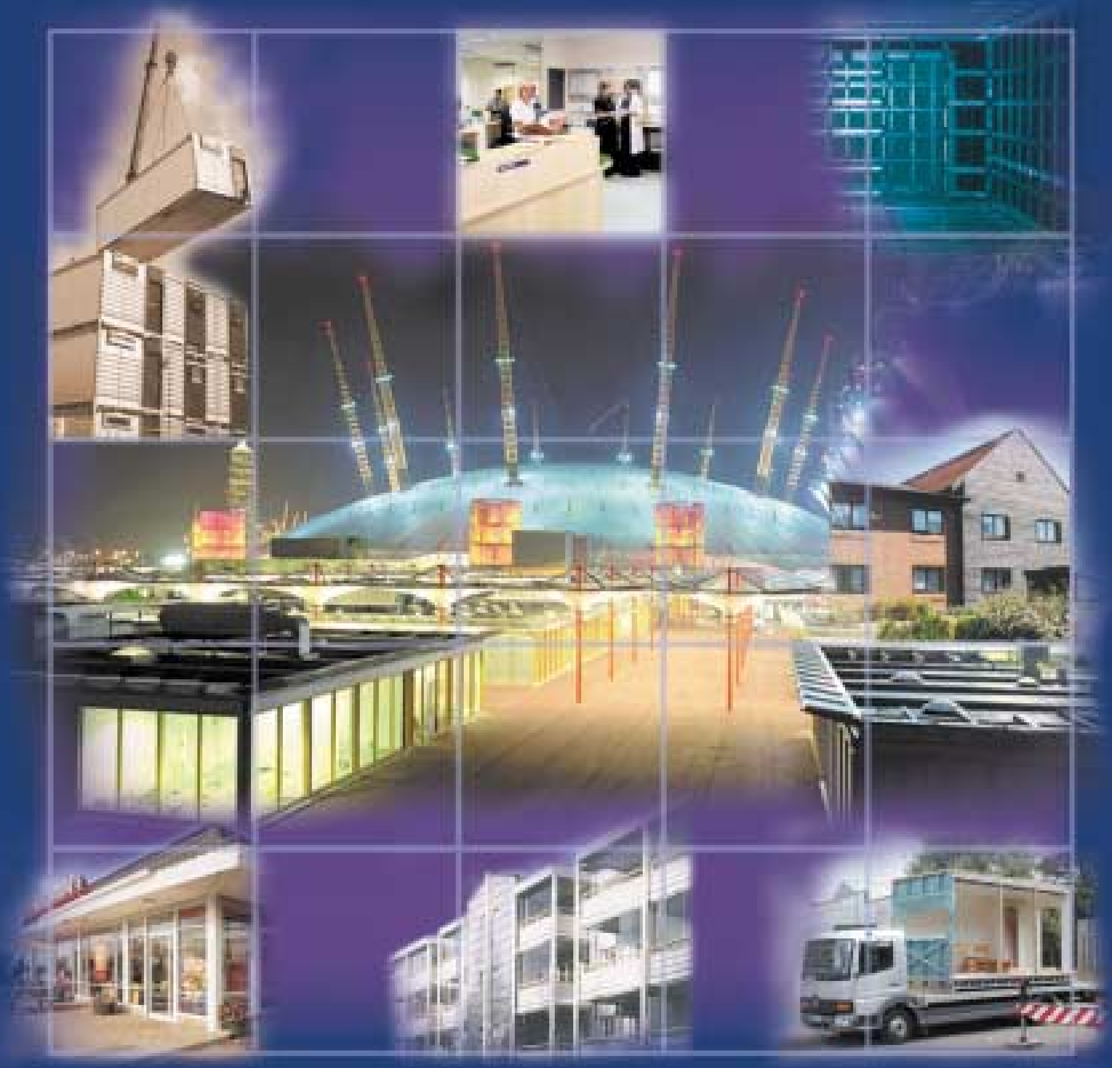


The Steel Construction Institute

Better Value in Steel

Value and Benefits Assessment of Modular Construction

Light Steel

USE OF MODULAR CONSTRUCTION IN THE UK

Why use Modular Construction?

Modular construction has been in the UK since the late 1970s but its rapid increase in recent years has occurred due to client demands in various well-defined sectors. There are five major manufacturers of modular units in the UK. A strong infra-structure of design, manufacture and supply exists, which has expanded to meet the increasing demand of the late 1990s.

The motivation for using modular construction generally arises because of over-riding client requirements for speed of construction, improved quality, and for early return of investment. Furthermore, there is a noticeable trend to use modular construction in social housing, where speed of construction is allied to economy of production scale, and to reduced disruption in congested inner city sites.

The optimum size and span of the modular units is dictated by transportation limits. Generally, buildings of up to 5 storeys can be designed without being over-engineered (i.e. the same modular unit is used at all levels without need for strengthening). For taller buildings, additional strengthening elements can be introduced.

Recent examples of the sectors that have used modular construction are presented in this study. A number of case examples of recent projects are presented in Case Studies on Modular Steel Framing (P271).

Better Value in Steel

VALUE AND BENEFITS ASSESSMENT OF MODULAR CONSTRUCTION

A L ROGAN BSc PhD, FBEng, PEng, MCIOB, MAPM, MASI
R M LAWSON BSc (Eng), PhD, CEng, MICE, MIStructE
N BATES-BRKLJAC BSc Arch, MA Urban Design

Published by:
THE STEEL CONSTRUCTION INSTITUTE
Silwood Park, Ascot, Berkshire SL5 7QN
Telephone: 01344 623345 Fax: 01344 622 944

In association with
OXFORD BROOKES UNIVERSITY
Gipsy Lane Campus, Headington, Oxford OX3 0BP
Telephone: 01865 741111 Fax: 01865 483073

CONTENTS

This publication is one in a series entitled Better Value in Steel. It presents on the results of a study into the value and benefits of Modular Construction using light steel framing. The data has been gathered from case studies in order to emphasise the value and benefits as obtained on real buildings.

Other SCI publications in the series are:

Value and Benefit Assessment of Light Steel Framing in Housing
(SCI publication P260, 1998)

Value and Benefits Assessment of Slimdek Construction
(SCI publication, 2000)

More detail on the use of modular construction can be obtained from:

Modular Construction using Light Steel: An Architect's Guide
(SCI publication P272, 1999)

The research was carried out by Dr Alan Rogan, Reader in the School of Architecture at Oxford Brookes University. The publication was prepared by Dr. Alan Rogan, Nada Bates-Brkljac from the University of the West of England and Dr. Mark Lawson of the SCI, with the assistance of David Phillips, Corus Colors.

The main contributors to the study were:

Andrew Horncastle	Britspace Building Systems Ltd
Stephen Trebble	Britspace Building Systems Ltd
Mike McLellan	Terrapin Limited
Nick Whitehouse	Terrapin Limited
John H Gaddes	Volumetric Limited
Simon Gardner	Volumetric Limited
Keith Blanshard	Yorkon Limited
Mike Sherwood	Yorkon Limited

Members of the Modular Framing Group also provided additional information.

The research involved gathering information from real projects and evaluating the reasons for use of Modular Construction using light steel framing relative to traditional construction.

Technical details on the use of Modular Construction may be obtained from:
The Steel Construction Institute, Silwood Park, Ascot, Berkshire SL5 7QN

Tel: 01344 623345, Fax: 01344 622944

Web site: www.steel-sci.org/lightsteel

1. EXECUTIVE SUMMARY

This publication provides information and data on the value assessment and financial benefits of modular construction using light steel framing. It is based on a background study in which a direct comparison was made between the benefits of buildings using modular construction and those built with traditional construction.

One part of the study involved case studies of seven projects using modular construction as the chosen structural option. From these case studies, the following key advantages may be attributed to modular construction using light steel framing:

KEY ADVANTAGES OF MODULAR CONSTRUCTION

Short build times
Typically 50-60% less than traditional on-site construction, leading to an earlier return on investment and saving in preliminaries.

Superior quality
Achieved by factory-based quality control and pre-design of similar modules.

Low weight
Compared to site construction, modular construction is about 30% of the weight of conventional masonry construction.

Economy of scale
Repetition of prefabricated units leads to considerable economy of scale in production.

Environmentally less sensitive
Efficient factory production techniques are much less wasteful and installation is less disruptive on site.

Use on infill sites
Modules are useful in small urban and infill sites, and in roof–top extensions to buildings.

Safer construction
Modular construction sites have proved to be significantly safer than traditional on-site building.

Reduced site labour requirement
The erection and finishing teams, which install and complete modular buildings, involve less workers on site than traditional buildings.

Reduced professional fees
Standardised design details for modular buildings simplify and reduce the need for specialist design input.

Services and bathrooms
Service modules can be used, even in traditional formed buildings.

The study has also identified additional benefits in line with the Egan (1998) Report, which challenged all aspects of the construction process to find appropriate solutions for improving performance.

The survey of the practitioners in the case studies has also identified the following benefits relative to conventional construction:

- ✔ Improvements in quality – reduced ‘call backs’
- ✔ Reductions in waste – reduction of site waste by 70%
- ✔ Faster construction time – speed increased by 50%
- ✔ Lower capital costs – reduction by up to 10%
- ✔ Better predictability – ‘just in time’ delivery to site

1. INTRODUCTION

There is a growing demand for the construction industry to provide better value by improved quality and performance. The 1998 DETR Egan Report ‘Rethinking Construction’ called for a culture of co-operation and greater innovation in procurement, design and construction, leading to demonstrable savings and benefits to the client, the contractor and to society in general.

Modular construction uses pre-engineered volumetric units that are installed on site as fitted-out and serviced ‘building blocks’. The use of modular construction is directly influenced by the client’s requirements for speed of construction, quality, added benefits of economy of scale, as well as single point procurement. These benefits may be quantified in a holistic assessment of the costs and value of modular construction in relation to more traditional alternatives.

Light steel framing is an integral part of modular construction as it is strong, light weight, durable, accurate, free from long-term movement, and is well proven in a wide range of applications. It is part of an established infrastructure of supply and manufacture and supported by British Standards and various design guides.

Modular construction is also widely used in Japan, Scandinavia and the USA, where light steel framing is the primary structural medium, and leads to flexibility in internal planning and robust architectural solutions. There are also important opportunities for modular construction in extensions to existing buildings either by attaching serviced units to the side of buildings, or by roof-top modules.

The practical use of modular construction was examined in seven case studies, in which the benefits were compared with the use of traditional building methods based on questionnaires and interviews with the designers and contractors in these projects.

Earlier, the Sir Michael Latham report (1994) stated “In a rapidly changing environment, both clients and the supply side are increasingly looking to improve performance and reduce and hopefully, eliminate conflict and disputes through a teamwork approach.”

The attributes of modular construction that are compatible with these objectives are:

- reduced construction costs, especially when combined with economy of scale production (10%+)
- much reduced construction time on site (50 to 60%)
- increased profitability of the industry due to economy of manufacturing scale
- increased site productivity (up to 50%)
- greater certainty of completion on time and to budget
- much reduced wastage in manufacture and on site
- greater reliability and quality

In the majority of buildings, there is a wide range of possible materials and construction systems that may be employed. The choice of primary structure is generally determined by initial cost, with less regard to functionality and performance characteristics. Previous studies have often failed to look at the whole building holistically, but have concentrated on the individual elements, without taking advantage of the whole process, and the impact following trades or components.

The mechanical services of buildings can present 20-40% of the building cost, where the structural framework and floors often represents only 8-15%. It is therefore essential to maximise benefits for the subsequent service installation, through better service integration and by designing the primary structure with this in mind.

1.1 Modular Construction using light steel framing

Modular or volumetric construction uses pre-engineered modular units, which are transported from the factory to the site, and are installed as fitted out and serviced 'building blocks'. The modular units may be room-sized or parts of larger spaces which are combined together to form complete buildings, such as residential buildings and hotels.

Light steel framing is an integral part of modular construction, as it is strong, durable, light in weight and dimensionally stable. It is used as the internal framework of the units to which a variety of cladding and finishes may be attached. The framework is sufficiently stiff and robust that it protects the internal finishes against damage during transportation and lifting into place.

The application of modular construction is most economic in the repetitive production of a large number of similar, often room-sized units where the economy of scale can be realised. Critical portions and service installations are made 'off the critical path' and where quality can be assured. Modular toilets, bathrooms, lifts, service plants etc. can also be introduced into otherwise conventional buildings.

The sizes of modular units are dictated by the economics of transportation, and units up to 4.2 m wide and 12 m long can be supplied. Units can also be provided with open sides to create larger internal spaces. All modular buildings are designed to be 'permanent' in terms of compliance with Building Regulations, although they are by definition relocatable and reusable.

Modular construction is also widely used in Japan, the USA, and in Scandinavia. In Japan, modular housing has achieved over 150,000 completions a year, and the light steel frame provides excellent robustness to seismic actions, and is not subject to rot or infestation.

In Scandinavia, modular construction has established a niche market in the renovation of existing concrete panel buildings, where external modular units are used to extend these buildings horizontally and vertically, and to increase their useful life and to create new habitable space economically.

Modular construction is driven by the two key imperatives: to build quickly on site, and to improve quality by off-site activities.

Both speed of construction and improved quality create business-related benefits to the client by early return on capital invested, or less 'down-time' in use of existing facilities in building extensions. 'Quality' implies fewer callbacks and in-service problems.

Increasingly, construction is seen as a dirty and disruptive operation, which affects neighbouring properties and the road network. Modular construction reduces the time on site, is much less noisy and produces negligible waste. Furthermore, deliveries to site can be timed to suit the local conditions.

The general benefits of modular construction may be expressed as those to the client, the contractor and to society in general. The economic benefits to the client can be calculated relatively easily, depending on the business-related costs. In renovation applications, modular units can extend the life of the existing building. Modular toilet and bathroom units, balconies, lifts and roof-top extensions can create new space and can improve the quality of life for the users.

1.2 Whole life costs

The capital costs of a building project must be extended to cover the operational costs and long term maintenance to create a holistic view of economics covering the whole building i.e. life (life cycle costing). Capital costs may be broken down into various components, some of which are dependent on the form of construction. Other elements of cost arise from the site infrastructure and supervision, known as 'site preliminaries' These aspects can be dramatically reduced from 15 to 20% in traditional projects, to less than 5% in modular construction projects.

A comparison between traditional (i.e. on-site) and modular construction is presented in Table 1. Modules are often delivered fully fitted, and the cladding and roof structure may be attached directly to the framework of the modules, which reduces the cost of a secondary cladding support structure.

Table 1. Comparison of traditional and modular construction in terms of capital cost (as percentage of the total cost).

Elements of construction	Traditional	Modular
External works and service connections	9	9
Foundations and sub-structure	7	6
Framework and floors	10	---
Modular units (fully fitted out)	---	50
Internal fitments	12	incl. in units
Roof structure and roofing	5	3
External cladding	15	10
Communal areas, access, stairs and lifts	8	8
Mechanical and electrical services	15	5
Drainage and rainwater	4	4
Site preliminaries, etc.	15	5
	100%	100%

1.3 Time related savings

Time related savings arise from three sources:

- Direct savings in site preliminaries.
- Earlier return on rental.
- Reduced interest charges.

Furthermore, in extensions to existing facilities such as hotels, schools and industries such as high technology production facilities, the reduced disruption costs to the business operation can be quantified.

In a typical hotel extension project, the savings due to the use of modular construction may be of the order of 20 to 25%, as described in Table 2.

Table 2. Savings due to use of modular construction in a hotel extension.

Basic construction cost	£800/m^2
Room rate per week (based on 70% occupancy)	£5/m^2
Time saving in construction	20 weeks
Financial benefit	£100/m^2
Loss of room bookings due to disruption (based on 20% loss)	£1.5/m^2
Conventional construction period	45 weeks
Equivalent saving	£70/m^2
Total saving	**£170/m^2**
Percentage of construction cost	22%

2. CASE STUDIES

2.1 Modular Steel Framing

Modular construction uses pre-engineered volumetric units that are installed on site as fitted-out and serviced 'building blocks'. Light steel framing is an integral part of modular construction.

The practical use of modular construction was examined in seven case studies, in which the benefits were compared with the use of traditional building methods based on questionnaires and interviews with the designers and contractors in these projects.

The following Case Studies illustrate the Value Assessment process as applied to the choice of modular construction to a wide range of building types.

The Case Studies using modular construction and the manufacturing companies involved are:

Sector	Name	Location	Manufacturer
Hotel	Travelodge	Western Avenue, London	Terrapin
Hotel extensions	Posthouse	Guildford and Cambridge	Volumetric
Hospital	Kingston-upon-Thames Hospital	London	Terrapin
Residential building	Murray Grove, Hackney	London	Yorkon
Retail buildings	Greenwich	London	Britspace
Educational building	Ashville College	Harrogate	Britspace
Student accommodation	Plymouth University	Plymouth	Unite

Case Study 1 – Hotel, Granada Travelodge, London

The Travelodge on the Western Avenue, London is a 64-bedroom building with undercroft parking. It is one of the largest Travelodges to be completed by Terrapin, and is created from the steel frame construction method named 'Prospex'. The modular design creates an exceptionally fast construction with a high degree of flexibility in application.

The Travelodge in West London is a five-storey building with public space on the ground floor and four storeys of en-suite bedrooms above. The building incorporates a breakfast bar and a lift as a variation from standard.

The site was very tight for the use of construction plant, and ground conditions were poor.

The main benefits of using modular construction in this project were:

- Good finished quality is maintained because the bedroom units are factory finished to an identical high quality.
- Site preparation was carried out in parallel with factory production, so on-site construction caused minimal disruption to the existing businesses and neighbourhood.
- Speed of installation of the units, and early start on cladding installation.
- Brickwork is tied back to the stacked modules without a separate support structure.
- Modular construction was cost effective for this 5-storey building.
- Higher than normal quality finishes were achieved on joinery products, through factory fitted secret nailing.
- The 64-bedroom hotel was built in just 27 weeks, the majority of this during the winter months.
- Serial partnering offered the customer the ability to call off the hotel at short notice, without delays through normal procurement routes.
- Economies of scale over the 300-bedroom programme reduced the manufactured cost of the units by 35%.
- Additional revenue because of the early completion of the hotel amounted to an extra £179,000 income for the hotel owners, based on 80% occupancy.

Case Study 2 – Posthouse hotel extensions, Guildford and Cambridge

The Posthouse hotel extensions were designed to match the traditional appearance of the existing main buildings, despite the novel nature of the new construction. The Guildford project is a 3-storey extension with 54 bedrooms and 12 fully-serviced modular units of 3.6 m width. The Cambridge project is 50 bedrooms.

Both projects used modular units fitted out by Volumetric & developed by Ayrshire Steel Framing and its consultants.

In the AyrFrame system, the thickness of the overall wall construction between adjacent bedroom units is reduced to 175 mm, including plaster and insulation. The combined ceiling/floor depth is only 225 mm.

The benefits of modular construction in these projects were:

- The existing operations of the hotel remained uninterrupted during the 12-week construction sequence.
- The extension was designed to match traditional appearance of the existing main block, despite the novel nature of the new construction.
- The thickness of the floors and walls is the minimum that can be sensibly achieved with modular construction.
- The modular design is repeated on other hotel projects.
- Increased revenue of £630,00, representing 20% of the project value.
- Minimised loss of car park space to the existing hotel clients.

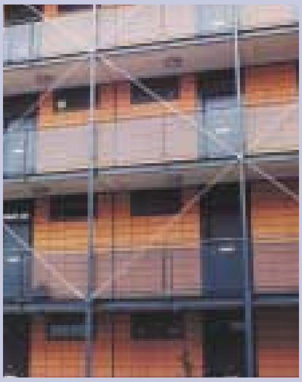
Case Study 3 – Hospital, Kingston-upon-Thames, London

This new hospital project used the Terrapin Matrex system, which is a hot rolled steel frame with light steel secondary members. The modular elements comprise the bathroom units and plant rooms. The elevation also demonstrates the flexibility of the modular system to accommodate a variety of wall finishes, cladding and architectural features.

The perimeter of the roof features both overhanging eaves, with traditional guttering and rain water goods, and a parapet with concealed guttering above the curved glazing to the corner.

- The overall fabric is highly insulated giving a very energy-efficient building.
- Modular construction enabled a much needed 132-bed hospital (6 surgical wards), fully supported with medical facilities, to be built in just 19 weeks.
- The original construction programme of 35 weeks was reduced to 19 weeks, reducing costs and providing hospital facilities quicker.
- Complex mechanical and electrical services were provided within the modular package, such as alarms, medical gases etc.
- A total design and build package was used, enabling single point responsibility, thus reducing design costs.
- Contract selection was through competitive tender, where the value and benefits of prefabrication proved the best competitive option.
- Construction nuisance, such as noise and dust, was kept to a minimum on this lively busy hospital campus.
- A pre-engineered plant room was fitted out off-site, saving eight weeks construction time.
- 7% potential saving on site preliminaries through faster build time.
- Potential savings made from not having to hire additional beds from the private sector could have given £2 m savings for the health authority.

Case Study 4 – Residential buildings, Murray Grove, Hackney, London



The Murray Grove housing project in Hackney, London was designed by architects, Cartwright and Pickard for The Peabody Trust. The client wished to procure a building that was architecturally interesting and met their requirements in terms of units of accommodation, low maintenance and speed of installation on site.

It is a 5-storey building on a tight corner site. It comprises Yorkon room-sized modules of 3.2 m width, in which two units made a one-bedroom flat and three units made a two-bedroom flat.

In the Murray Grove project, the cylindrical stair tower, external access balconies and mono pitch roof were all prefabricated. Stability to the access walkways was provided by external bracing, although the modules are stable as a group.

The external façade consist of clip-on terracotta tiles.

The criteria for using modular construction were:

- The client wished to develop this scheme as a demonstration project on social housing using modular construction.
- A quality architectural image was critical to the client in order to overcome the possible utilitarian perceptions often associated with system-build housing.
- There is a potential market in inner city housing projects where there are constraints on the construction operation.
- The need to avoid disruption to adjacent buildings and road system.
- Early rental income, giving additional revenue of £58,500 in comparison to traditional building.
- Additional accommodation provided through modular development, giving 21 more units than adjacent developments, with an extra income of £3,150 per week or £9.8 m over the building life.
- Increased asset value, through greater better quality development, corresponding to an extra £4.02 m in asset value for this project.
- Better development of diminishing land resources, yet maintaining high quality desirable accommodation.

Case Study 5 – Retail buildings, Greenwich, London

The project was designed by Sir Richard Rogers Partnership as part of the Millennium Dome project. The buildings were required to be high quality and to be used for a range of applications.

Important features:

- Wide range of retail outlets and offices.
- Quality architecture for this important public project.
- The modular buildings require only lightweight foundations for use on the former industrial site.
- The flexibility of the modular system meant less site disruption, and other structures could be built around them without delay to the schedule.
- The entire complex of buildings can withstand the rigors imposed by up to 30,000 visitors per day.
- All McDonald's modules are developed so that they can be re-used on other sites, maintaining the asset value of the building.
- Installation had to be rapid to meet the opening date.

Case Study 6 – Educational building, Ashville College, Harrogate

The new building comprises a 900 m^2 single storey steel frame modular structure with six classrooms and an additional special needs classroom, dining room/sports hall, boys and girls toilets, hall, library, staff offices and toilets and store room. Britspace acted as principal design and build contractor throughout.

- Minimal disruption to the school operation.
- Construction period fitted into school vacation, 20 weeks earlier than conventional building.
- Good space provision for education uses.
- Robust, long life construction.

Case Study 7 – Student accommodation, Plymouth University, Plymouth

This is the first project in the UK in which modular units will be used for the developer, Unite, in the renovation of an existing building. In this project, 50 modular bedrooms will be constructed using Corus Framing's Surebuild system. The bedrooms are designed with an open side so that they could be placed together to minimise the wall thickness.

The bedroom units will be lifted out onto the roof of the existing 4-storey 1930's concrete building. The new pitched roof will be supported by the modules. The project will be on site in October 2000.

The advantages of modular construction in this type of renovation project are:

- Light weight to avoid over-loading the existing roof structure. The units weigh less than 1 kN/m^2.
- Speed of installation to meet a tight programme and minimise disruption. The units can be installed in less than 10 days.
- Design, build, operate and finance service is available for the educational sector.
- The same design of student bedrooms can be used for other projects.
- Robust construction for student accommodation.
- A combination of modular units and light steel framing will be used for communal areas.
- Roof structure can be supported directly by the modules with no separate structure or purlins.
- Will provide an additional 1,000m^2 of accommodation some 75% cheaper than traditional construction.
- Modules will be lifted into their required position with minimal disruption.
- No additional scaffolding is required.

3. VALUE ENGINEERING ASSESSMENT

The study examined the use of modular construction on several projects compared to traditional materials.

Further information on modular construction, and light steel framing in particular, can be found in a number of publications issued by The Steel Construction Institute.

The motivation to use modular construction arises from various well-defined client benefits. The value attached to many of these benefits is dependent on the particular client and on the building use and location.

Various common themes emerge which can be taken into account in a value engineering assessment of factors that are normally not included in a conventional Bill of Quantities. Adding value by standardisation and pre-assembly is discussed in a CIRIA report (176). The values and assessment of light steel framing in housing is discussed in an SCI publication which includes the economic benefits of speed of construction.

3.1 Speed of construction on site

The cost saving due to speed of construction on site may be quantified as:

Reduced site preliminaries including hire of site huts and other facilities, etc.
Typically site preliminaries are estimated as 8 to 15 % of the total construction cost. Therefore, a 50% reduction in time on site can lead to a commensurate saving in preliminaries cost to the contractor. Although site preliminaries are identified in the Bill of Quantities, the benefit of these savings to the client is not necessarily apparent.

Earlier return on investment to the client.
This benefit depends on the business operation, but the minimum level of this benefit is the saving in interest charges on the cost of the land and the average construction cost over the reduced construction period. The maximum level of this benefit is the earning potential of the building when in early operation.

Loss of the earning potential of the existing facility.
This is a real cost to the client that occurs particularly where existing buildings, such as hotels, are extended or modified. A reduced construction period will lead to commensurate savings to the client.

Predictability of construction programme (i.e. low risk of over-runs).

The total benefit of speed of the construction operation can be in the range of 5% to 10% of the total building cost when calculated from the time saving on site in comparison to more traditional site-intensive construction systems.

3.2 Benefits in the construction operation

Normal construction operations are often constrained by the features or locality of the site. Modular construction can lead to considerable benefits in the construction operation and can reduce or alleviate many common problems that may be encountered, such as:

- Limitations on delivery of materials to site in terms of time of day and impact on traffic in the locality.
- Working time and other restrictions in sensitive sites (often inner city locations).
- Noise limitations due to the construction operations, particularly adjacent to existing buildings.
- A short 'weather window' for construction, for example in an exposed or inhospitable location.
- Lack of suitable site trades or the cost of transporting workers to a remote location.
- Lack of working space around the building for site storage, site huts etc.

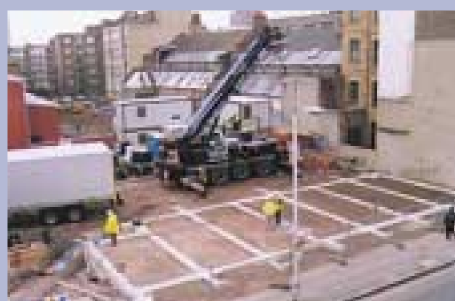
These constraints are often site specific but in themselves can be important in determining the method of construction. The opportunities for use of modular construction should be investigated early in the decision-making process in order that these factors can be quantified.

Other economies in the construction operation using modular construction may be quantified in a holistic cost study as follows:

- Less wastage and lower costs of disposal of waste materials.
- Less daily use of cranage, as the installation of the modular units can be carried out by a heavier crane that is hired for a short period.
- Fewer site operatives, potentially requiring fewer site facilities etc.

These economies are independent of the site constraints but may be amplified considerably when combined with difficult site conditions, or avoidance of disruption to neighbouring properties, particularly in inner cities. These may be classified also as environmental benefits.





3.3 Economy of scale

Regular bedroom and bathroom units can be produced to standard dimensions and specifications that are readily transportable. In this case, there are economies of scale, and speed and quality benefits through factory production and pre-testing.

The economy of scale in production therefore leads to the following benefits:

- Greater investment in the production-line operation, leading to greater speed of assembly.
- More emphasis on improvement in design by testing, and by rationalisation of details based on ease of manufacture.
- Establishment of strict quality assurance procedures and avoidance of re-working.
- Better design, including the possibility of variants at modest additional cost or difficulty.
- More involvement of specialist suppliers, e.g. services.
- Reduction of waste by efficient ordering and use of materials.

On the debit side of this argument, it should be noted that:

- The structure may be 'over-engineered' for its normal applications due to requirements for lifting and transportation.
- The need for 'standardisation' means that some economy in use of materials is sacrificed for production efficiency.
- Costs increase with the number of non-standard units in a given project.

In all cases, economy of scale will increase with greater standardisation and production line efficiency.

Testing of standard modules can lead to system approval, which overcomes the need to repeat design calculations for a wide range of otherwise similar projects.

3.4 Quality issues

Quality is often the crucial issue to the client who is concerned about the subsequent operation of the building.

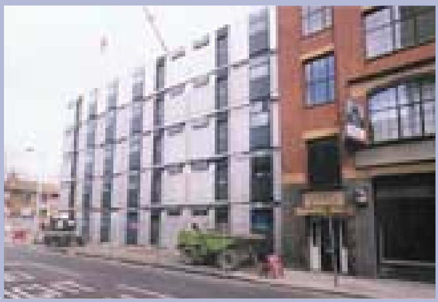
The following aspects of modular construction have strong influence on quality:

- Some clients demand a high degree of quality assurance for their business operations and the single point procurement route concentrates the responsibility on the manufacturer.
- In modular construction, off-site trials can be carried out to 'prove' the system before installation. This is particularly true of highly serviced units such as plant rooms, lifts and kitchens.
- In conventional building, many contractors also allow 1 to 2% costs for 'snagging' and 'call-backs'. These costs are considerably reduced when using modular construction, in comparison with site construction.
- Light steel framing is robust and does not suffer from deterioration in performance. Movements are minimal, which avoids cracking of finishes.

3.5 Application to renovation

The renovation sector represents over 40% of the construction market and has its own features in terms of construction operation. The particular benefits of modular construction in renovation are:

- Reduced disruption in difficult sites. Units can be lifted easily into place.
- It may not be necessary to move the occupants during the renovation work (true of roof-top extensions).
- Modular units are light in weight and extensive strengthening of the existing structure is not required.
- Less scaffolding and temporary works are required, as external modules are self-supporting, and roof-top modules can be lifted into place.



4. ECONOMIC ASSESSMENT

4.1 Economic assessment

A full economic assessment was made of a 4-storey residential building comprising 30 apartments, using 60 modular units that is constructed in central London. The project is compared to traditional brick/block construction in terms of its finished cost and the impact of speed of construction and site processes.

The economic assessment was split into two parts:

1. **Cost assessment.** The actual costs of using modular construction were compared to 'traditional' construction as established through a Bill of Quantities.
2. **Financial assessment.** The financial benefits to the user are established through the financial model. These benefits are related to speed of construction and improved cash flow.

The most important financial aspects of the assessment using the Modular system that are quantified in the study are:

- Savings in construction time with improved quality, leading to reduced site preliminaries and expensive call-backs.
- Reduction in financing cost, by earlier return of initial capital, with quicker and higher income from rental, less cost of temporary accommodation and increased asset value.

4.2 Cost assessment

In order to establish realistic costs of modular construction compared with traditional construction a Bill of Quantities was produced for a typical 4-storey residential building, based on site information and known date.

The Bill of Quantities costs for two types of construction methods are given in table 3.

4.3 Financial assessment

This part of the study covered the calculation of the financial benefits resulting from the speed of construction, and the effects on working capital. The net saving established is attributable to the savings due to using modular construction in comparison to traditional. The evaluation was carried out by establishing a computer spreadsheet model that accepts all relevant input data and then determines the consequent financial savings.

The first part of the study considers the project as a commercial development for sale demonstrating the financial advantages through a spreadsheet model. The second part examines the earlier return through rental income.

The third part examines increased asset value through improving the quality of the development.

Table 3. Bill of Quantities for a typical 4-storey residential building in London.

Bill item			**Modular construction £/m²**	**Traditional construction £/m²**
Substructure			**66**	**66**
Superstructure:	Modular dwelling units		529	
	Traditional construction			450
	Other frame components (to stair tower)		92	92
	Upper floors, access walkways ad balconies		25	25
	Roof		30	30
	Staircases (communal)		10	10
	External walls (cladding)		93	93
	Windows and external doors		5	5
	Internal walls and partitions		20	20
	Internal doors		2	2
		Group Element Total	**806**	**727**
Internal Finishes:	Walls		0.5	0.5
	Floors		0.5	0.5
		Group Element Total	**1**	**1**
Services:	Landlords electrical installation		11	11
	Communication installation		12	2
	Lift installation		16	16
		Group Element Total	**29**	**29**
Preliminaries			**70**	**105**
Contractors' design fees, Insurances etc			**42**	**42**
Scaffolding				**18**
Call-backs				**7**
Additional skips				**2**
		TOTAL	**1014**	**997**

Cost data supplied by Keith Bowler, The MDA Group.

4.4 Basis of the spreadsheet model

For the spread sheet, the model accepts various input variables that define the size of the development project, the mix of housing, the cost of land, and the basic cost of construction. Other factors such as interest rates, fees and other expenses are also entered. If appropriate, a 'premium' for modular construction can be included, but in the study this was set at zero so that the financial benefits from speed of construction would be isolated.

From the input data, the cash flow for each type of construction is calculated on a month-by-month basis. Construction costs are assumed to be uniform over the whole development period. Sales revenues commence after the show dwelling has been completed. All these values and the findings of all the expenditure, including interest, are given on separate output sheets for the two forms of construction. The key features of construction and development periods, profitability and cash requirement for the two types of construction are compared on a fourth sheet and the benefits of modular construction are expressed in percentage terms.

The financial model was based on the Nationwide Building Society's quarterly sales data and the Royal Institution of Chartered Surveyors; indices for regional building costs, which give regional variations. The sales value used for this region is £304 per square foot based on figure supplied by an independent local estate agent.

The interest rate used in the model is 1% above the Bank of England base rate for Group 1 developers, rising to 3% over Bank of England base rate for Group 5 developers. (Group 2 was assumed and a rate of 8.5% (7% + 1.5%) was used in the study.) When cash flow becomes positive, interest on money earned is calculated at 3% below the applicable borrowing rate.

Input and output spreadsheet pages for the case study are given in the Appendices. The sheets show further details of costs, such as fees, cost of the show-house, etc.

The case study consisted of 30 flats. The construction periods are 9 months for traditional and 6 months for modular construction. Construction was assumed to start 4 months after procurement of the site. The financial savings resulting from the use of modular are summarised in Table 4.

4.5 Earlier returns through rental incomes

The saving of 3 months on the development period has enabled the authority to receive an earlier income. The average rent for this development is £150 per week. A saving of 13 weeks in construction leads to £58,500 extra income.

Taking into account the financial assessment benefits it can be seen that they outweigh these:

Time related benefits:	£37,171 or £17/m^2
Increased rental:	£58,500 or £27/m^2

The net saving in modular construction is therefore £27/m^2 when all the financial benefits are taken into account.

4.6 Increased asset value

Improved quality of construction, and the density of the development increase the asset value of the building.

Asset value of the project, including 30 apartments, has been estimated at £6.2 m.

The cost summary is as follows:

Modular construction:	£1015/m^2
Traditional construction:	£997/m^2
Difference:	£18/m^2

Table 4. Financial savings resulting from modular construction

	Traditional	Modular	Difference		Other benefits
Construction period	9 months	6 months	3 months shorter	33% faster	Savings on preliminaries
Development period	13 months	10 months	3 months shorter	23% sooner	Release of developers investment
Sales start	7 months	5 months	2 months earlier	29% sooner	Quicker return on capital
Profitability	£4,639,137	£4,676,308	£37,171 more profit	0.8% higher	Benefit to the builder
Internal rate of return	222%	316%	94% higher	43% increase	Benefit to the builder
Peak cash required	£1,910,677	£1,787,022	£123,655 less	6.5% lower	Benefit to the builder
Average cash required	-£180,569	-£410,648	£230,079 less		Lower borrowing
Turnover using same capital (Ratio of development period x peak cash)				39% extra	Ability to expand

5. ENVIRONMENTAL BENEFITS

5. Environmental benefits

Steel construction, and particularly light steel framing, has the following environmental benefits:

- Steel is very efficient as a structural material and a relatively small quantity of steel (expressed as kg/m^2 floor area) achieves spans of high-load bearing capacity.
- Light steel framing is light in weight and can be handled easily on site without expensive equipment.
- Galvanised steel sections used in light steel framing have consistent properties, excellent durability and do not deteriorate or rot in an internal environment.
- Steel construction is adaptable to change of use by bolting on or welding attachments, cutting openings, strengthening, etc.
- All steel can be recycled, and indeed up to 50% of new steel production is currently from old scrap steel.
- Steel sections can be salvaged and re-used easily.

Modular construction has distinct environmental advantages over more traditional site-intensive construction from the point of view of:

- Energy use in manufacture.
- The construction operation.
- Energy use in service operation.
- Relocatability and re-use of the modular units.

The SCI publication 'The Role of Steel in Environmentally Responsible Buildings' sets out the merits of steel in context of the building industry's impact on the environment and includes the benefits offered by light steel.

5.1 Environmental benefits during the construction operation

The main environmental benefits during the construction operation are derived from the shorter construction period, which lessens the impact on the local environments. Waste is drastically reduced because of efficient factory production, and the reduced damage or use of packaging materials on-site. There are other local environmental benefits of the construction operation, which are identified as follows:

- Site installation of the modular units is a rapid and quiet operation that can be done 'just in time', with no requirement for site storage or additional noisy equipment.
- The delivery and installation of the modular units can be timed to observe any site working or road traffic constraints.
- The delivery of a large number of relatively small amounts of site materials is much reduced.
- Less waste is created so dumping of material waste from site is much reduced to less than 30% of a conventional project. Foundation excavation is minimised and there are fewer potentially wasteful site activities.
- Materials are used more efficiently, with considerable economy of use in production than is achievable on site.
- The main construction operations are less disruptive to adjacent or connected properties in terms of pollution and associated nuisance, etc.

5.2 Environmental benefits in use

The environmental benefits in use concern the high level of performance that can be achieved economically, as follows:

- Good acoustic insulation is provided due to the separation between the modules.
- Good thermal insulation can be provided easily in light steel framing by creating a 'warm frame'. These buildings are very efficient thermally, leading to reductions in energy use and consequent CO^2 emission.
- Modular units are very stiff and strong, due largely to requirements for lifting and transportation, and therefore have a solid 'feel'.
- All light steel framed structures require minimal maintenance and no call-backs for shrinkage, etc.

5.3 Environmental benefits in re-use

The benefits in terms of re-use are:

- Modular buildings can be extended easily (or reduced in size) as demand changes.
- Modular units are fully relocatable at modest cost, with consequent reduced energy cost in dismantling, and no wastage of materials.
- Long-term use of scarce resources is reduced.

6. DESIGN AND PROCUREMENT PROCESS

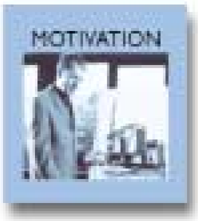
6.1 Decision making process

The decision making process for modular construction differs from more traditional methods of construction because of:

- The close involvement of the client in assessing the business-related benefits of the choice of the methods of construction.
- The direct involvement of the manufacturer in terms of the design, costing and logistics.
- A close working relationship between the manufacturer and main contractor in terms of delivery and site installation.
- The need to make key decisions early in the procurement process (as such decisions would be relatively expensive to modify later).
- The important environmental and site related benefits that can be achieved (such as reducing the impact on neighbouring properties and site traffic).
- The effects of transportation logistics on costs and sizes and on the inter-relationships of modules.

Because the benefits of modularisation are realised through prefabrication, the initial space planning, subsequent detailed design, and service integration and co-ordination are critical. There is less capacity for significant spatial, material or structural alterations at a large scale. The design needs to be fully complete prior to the commencement of manufacturing.

A recent BSRIA Report defines six 'building-blocks' in the successful use of modular or pre-assembled construction, as follows:



Motivation that the client and design team must be strongly motivated to use modular construction at the early stages of the process.

Design means that modular construction must be considered early in the design process, and that the economy of scale must be achieved through design.

Procurement is the process by which the design is realised through a series of manufactured products before they are delivered to site, and assembled to create a functioning unit.

Logistics concern transportation and assembly (and possibly later disassembly) and also 'just-in-time' delivery to site.

Site installation relates to the physical method of installation, and assembly on site, including formation of larger units and attachment of ancillary components such as cladding and services.

Testing and commissioning are important for highly serviced units, which can be partially carried out off site.

Often clients choosing to use modular construction have had previous experience of its success either with the same team or with other UK or overseas modular projects. However, for clients to whom the technology is new, the decision-making process is even more important. Direct involvement of the client, manufacturer and main contractor (if different) is important at the concept stage of the project.

For the full benefits of modular construction to be realised, the notion of volumetric/modular building must be considered at the conceptual stage of a scheme. The design development can then harness all the aspects of a modular approach, including requirements for production and interfaces with other components of the building.

6.2 Procurement process

Procurement defines the process from completion of design to the successful commissioning of the assembly or building. It includes the process by which components are both manufactured off site and installed on site, and is therefore time-related from the point where design decisions are made.

Procurement is also represented by contractual and financial arrangements although these are dependent also on the parties involved. In modular construction, the procurement process involves the specialist manufacturers who see the process in manufacturing teams by pre-ordering of materials, setting up production-line assembly, production efficiency by suitable level of automation, and temporary storage and delivery to site on 'just-on-time' basis.

There are several ways of procuring modular buildings. Indeed some companies offer the complete turn-key package, providing design, manufacture and erection services. However, in many projects, the client will appoint an architect who is responsible for the overall design and coordination of all the inputs from specialist manufacturers.

Two procurement methods are most commonly used:

- The architect may specify the manufacturer who will undertake the work and this will enable the parties to work from inception to completion. The architect may select the manufacturer by competitive interview, track record or reputation.
- Alternatively, the architect may draft a performance specification for the works, which is usually done in consultation with one or more modular manufacturers. This is then used as a basis for tendering, either through a main contractor or directly to the modular specialists.

It should be recognised that each manufacturer undertakes the construction of its modules differently. They will be prepared to offer advice and provide detailed drawings but may not wish to divulge commercially sensitive technical details. Importantly, the 'lead-in' time required for prototype, design and manufacture of bespoke modular units should be considered, although detailed design of the modular units can be carried out in parallel with other design activities. If the module configuration is repeated from other projects, then design and prototyping time is much reduced.

The lead-in time required from ordering to delivery of the modular units can be as short as 6 to 8 weeks if the modular units have been 'prototyped' previously on similar projects and the production logistics are well established. Even in a typical regular hotel project, there can be 8 different modular units representing internal, end bay, rooftop, and left- and right-handed units. However, the floor configuration of all units is essentially similar.

For buildings in which modular construction is being considered for the first time, sufficient time should be allowed for manufacture of pre-production prototypes, which help to resolve potential design and production problems. A period of 4 to 6 weeks should be allowed for this prototyping stage. The sensible 'lead-in' time for delivery of the modules might therefore increase to 10 to 14 weeks. At this point the design is frozen; changes will lead to delays and possible additional costs.

(see chart on opposite page)

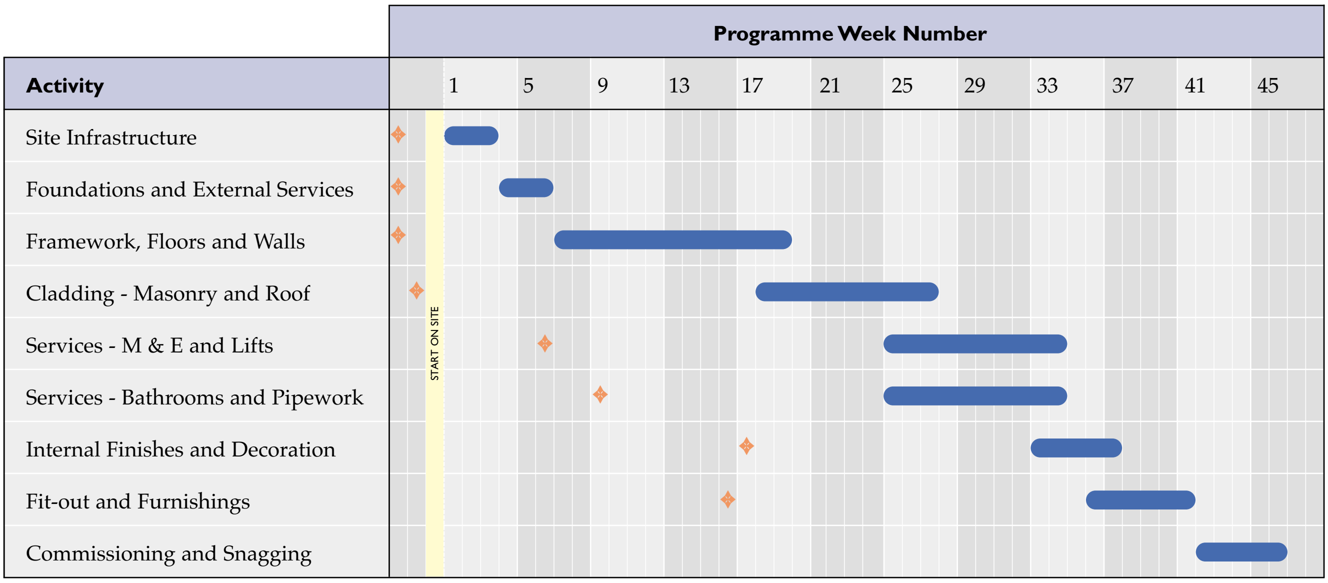
Often it is ordering of the lifts and any complex plant that determines the effective completion of the project rather than the production of modular units. A lead-in of 18 weeks is allowed for lifts but can be reduced significantly if the modular manufacturer has arrangements with particular lift suppliers. Loose furniture is often moved in later whereas fixed furniture is installed in the factory.

It is apparent that the on-site construction period might be reduced from 47 weeks for conventional construction to 33 weeks for light steel framing with prefabricated bathroom pods and to 22 weeks for entirely modular construction. Timesaving can be even greater on real projects.

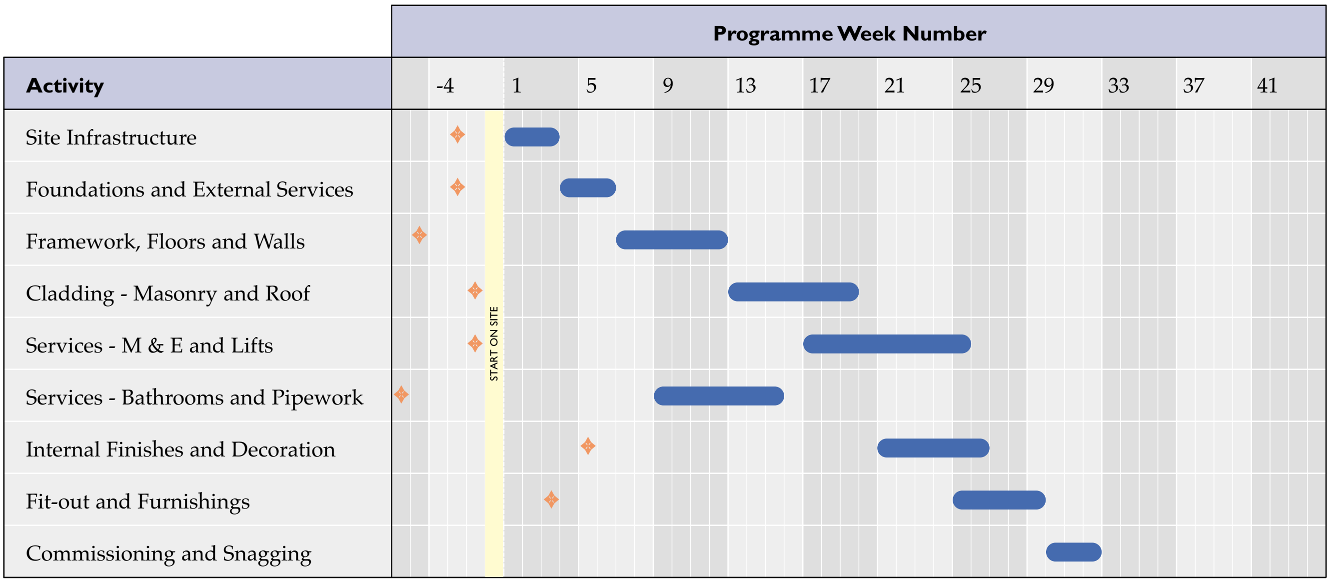
However, the pre-site ordering period can increase from 3 weeks to 6 and 8 weeks respectively for the various degrees of modularisation, which is also dependent on the ordering of the major services, cladding and fitments. However it is evident that the total time from ordering to completion is much reduced, which effectively means that the variable site activities are replaced by more quality controlled and faster factory operations.

These approximate construction and lead-in times are not intended to be definitive but rather emphasise the importance of the decision-making process when using modular construction.

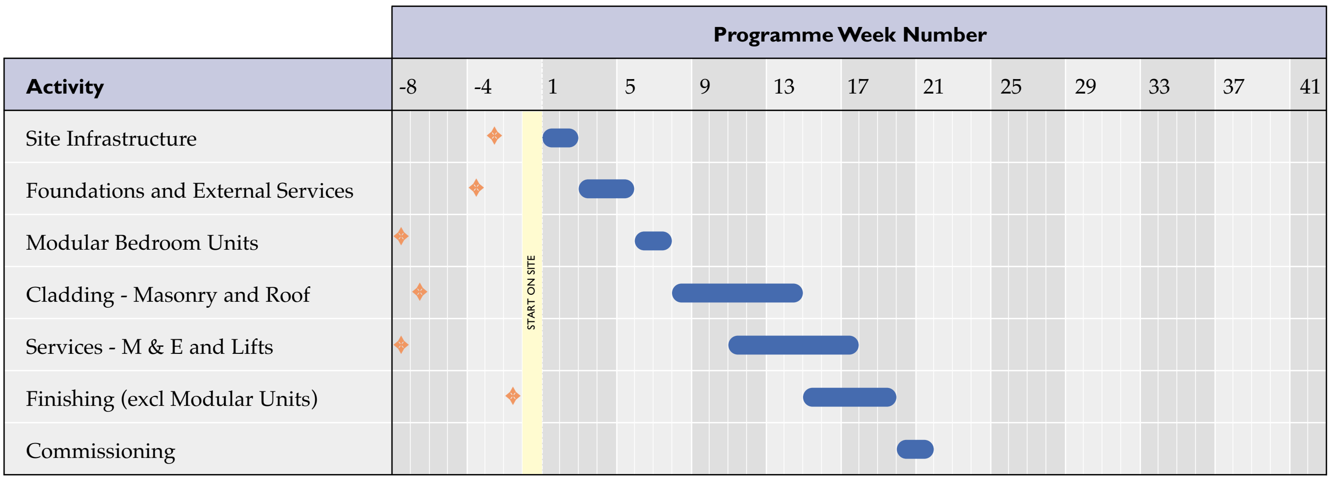
Conventional On-Site Construction



Light Steel Framing and Modular Bathroom Units



Modular Construction



✦ = *Time of ordering*

7. CONCLUSIONS

In this study the benefits of modular construction have demonstrated its ability to be cost effective against other methods of construction, and has led to financial savings and reduced disruption on site.

The following conclusions may be drawn from this study on the value benefits of modular construction in new build and renovation:

- Modular construction offers considerable benefits to the developer or builder in terms of speed of construction, the ability to pre-plan the construction phase of the work and reduced callbacks. Modular also offers a highly cost effective solution for medium rise buildings eliminating the need for a separate independent structural frame.
- Speed of construction leads to the following potential savings in construction costs:

  - a reduction in preliminaries.

  - a reduction in plant usage.

  - reductions in site disruption.

  - earlier rental or sales.
- Speed of construction also leads to reduce financing costs, as a result of earlier return on capital, and improved cash flow.
- Improvement in quality leads to increased rental potential or sales as well as better customer perception.

In this research study, it was demonstrated that the savings in construction costs and real benefits to the developer/user were:

Case study 1:
Hotel, Granada Travelodge, London.

- A 35% reduction in cost through economies of scale.
- Additional revenue of £179,000 through speed of construction.
- Building a 64-bedroom hotel in just 27 weeks on site.

Case study 2:
Posthouse hotel extensions, Guildford and Cambridge.

- Enabled the busy existing hotel to be fully functional during construction work.
- Reduced construction period of only 12 weeks on site.
- Excellent acoustic insulation.

Case study 3:
Hospital, Kingston-upon-Thames, London.

- 132 bedroom (6 surgical wards) hospital built in just 19 weeks, saving 16 weeks on original programme.
- 7% saving on preliminaries through faster build.
- Earlier occupancy had a potential saving of £2 m through not having to rent beds from the private sector.

Case study 4:
Residential buildings, Murray Grove, Hackney, London.

- Additional revenue of £58,500 in rents due to completion in only 40% of the time of conventional construction.
- Increased asset value of £4.02 m through higher quality development.
- Additional rental income through higher density development.

Case study 5:
Retail buildings, Greenwich, London.

- Ability to achieve high quality architectural design.
- Certainty to deliver to meet opening date.
- Ability to re-site units in the future.

Case study 6:
Educational building, Ashville College, Harrogate.

- Speed of construction to achieve tight programme.
- Single point procurement.

Case study 7:
Student accommodation, Plymouth University.

- Speed of construction to achieve tight programme to meet University term start.
- Provision of an extra floor at minimum cost.
- Minimal disruption to existing facilities.
- No strengthening of the existing structure.

1. **Terrapin-Prospex**

Terrapin specialises in light steel framing systems and modular buildings of various forms. The Prospex system uses C-sections of 100 to 210 mm depths, which are assembled together with various hot rolled steel components to create the modules. The units are continuously edge supported but are lifted from their corners. The walls are braced by cross-flats.

The system is based on internal module widths of 2.7 and 3.5 m, with span increment of 600 mm up to a maximum of 9.6 m. A variety of cladding materials can be used. This modular system has been used for a wide range of building types, including sheltered accommodation and hotels for the Travelodge chain. Bathroom and toilet modules are also produced for hotels and other highly serviced buildings.

Terrapin have also developed a cassette cladding system, which has a rigid backing so that panels up to 1.5 m wide can be manufactured. This system has been used in new buildings, and over-cladding of existing buildings. Recently, Terrapin has developed a system of composite construction that has patented shear connectors fixed to light steel sections.

Terrapin also offer a main contractor role and markets a structural system called Matrex, which is built conventionally using long span hot rolled and light steel secondary beams.

2. **Ayrshire Steel Framing**

Ayrshire Metal Products plc produce a wide range of light steel components for use in the building industry. The company's two principal products used in the building industry are the Ayrshire Steel Framing system and the Swagebeam system.
In the context of modular construction, two forms of structure have been developed:

- Conventional framing using load bearing wall panels, which are bolted or welded together and are supported at their corners.
- The AyrFrame system, which is based on a series of transverse box frames with longitudinal members providing the necessary stiffness in this direction.

The AyrFrame design uses moment-resisting light steel frames that are connected longitudinally by top hat-shaped 'furring' runners and corner angles.

No bracing members are required as the multiple connections of the furring member provide the necessary in-plane stiffness. The ends of the modules are closed with prefabricated panels. The walls are finished with two layers of plasterboard and can be as thin as 100 mm. The floor comprises 22 mm cement bonded particle board, which is moisture resistant, and improves the acoustic insulation of the floor. The roof of the unit comprises water-resistant chipboard. The AyrFrame modular units have been used in recent hotel projects. The system has also been used for various residential buildings that are cellular in from. The AyrFrame units can be manufactured to suit particular applications, as they can either be fitted out in a separate off-site process or finished on site.

3. **Volumetric**

Volumetric is part of the Potton Group and has a long history of modular construction, firstly using timber framing, and now using light steel framing. In recent years, Volumetric has concentrated on the hotel market, particularly for THF Post House Group.

The Potton Group offers a 'turn-key' design and build service. The modular units in recent projects were manufactured using AyrFrame system, and were fitted out in-house by Volumetric.

4. **Yorkon**

Yorkon Ltd is a sister company to the larger Portkabin Ltd and provides permanent buildings by single point procurement. Yorkon offer a building system based on two generic module types: the Yorkon building module and the Yorkon room module.

The Yorkon building module uses light steel framing and is suitable for structures up to 4 storeys high. It is based on a standard 2.94 m wide module with lengths up to 14.7 m. Modules of 3.8 m width can also be manufactured for use in low-rise buildings, but may require special transport. A wide variety of internal and external finishes may be applied. The system has BBA certificate, which covers a 60 year design life. It has been used for offices, hospitals and educational buildings.

The system is based on 355 mm deep light steel floor beams and 150 mm floor joists. Four 100 mm square SHS members are used at the corners, and a variety of infill walls and cladding types may be used. Internal module heights are 2.5 m, 2.7 m and 3.0 m. The standard open sided modules may be assembled to form larger spaces of up to 12 m internal span (using a separate internal post).

Yorkon has also developed its own room module, which spans between facade walls and across the internal corridor. It utilises the principle of stressed skin design by using the shear resistance of flat steel sheets attached to the sides of the units to create a stiff 'box'. In hotel construction, the modules comprise two rooms, and the corridor between them. In this system of monocoque construction, the module width may be in the range of 2.5 to 4.1 m, with internal lengths of 9.6 to 16.8 m in 1.2 m increments. The units may be stacked up to 6 storeys high.

5. **Britspace Modular Building Systems**

The Britspace Modular Building System uses steel hollow section columns at the corners of the units and at 4 m intervals along the units. Floors, wall and roof members are galvanised steel C sections, and the wall members are bolted to the longitudinal floor and roof members. The flooring material is 28 mm moisture-resistant cement particle board. The walls and ceiling comprise two layers of fire resistant plasterboard to give 60 minutes fire resistance.

The system is offered with BBA certification for both residential and commercial buildings. Britspace and Yorkon have developed modular systems for use in fast-food restaurants for the McDonald's chain. These modular units are fitted out before delivery to site and connected together on site to form the complete building with minimal additional work. The foundation details are specially designed to facilitate site connections to light steel piles that are suitable for all ground conditions.

7. **Unite**

Unite is a design, build, finance and operate company which concentrates in the health and educational sectors. Unite has developed, together with Corus Framing, a modular study bedroom using light steel panels and floor joists from the Surebuild system. Their niche market is in student residences and accommodation for health and other key workers, particularly in inner-city locations.

Together with the Unite subsidiary, Unite Finishes and the design and built arm of the group TNG, they carry-out the on-site installation and construction of the completed building.

The modular bedroom units are 5.1 m long and 2.4 m wide, constructed using panels comprising 75 mm deep and 1.6 m thick Surebuild studs and 225 m deep lattice Surebuild joists. The modules can be constructed with an open side, so that adjacent modules could be placed together to minimise on the internal wall thickness to meet the tight internal planning requirements. The wall used two layers of Fermacell board for rigidity and sound insulation.

This form of construction can be used in new-build and or renovation projects. Unite provides a unique finance, maintain and operate service, and uses modular construction in many of its new-build and renovation projects.

8. **Corus**

The Surebuild system has been developed by Corus Framing and has been widely used in the construction of 2 and 3 storey houses. It comprises of 75 mm C section studs and either 150 mm Sigma section floor joists, or 225 mm lattice joists for long span applications. Wall panels are manufactured in the factory and can be easily lifted into place on site.

Wall and floor panels are also used in modular construction (see Unite), and can be used in renovations applications and roof-top extensions. An open habitable roof system has been developed for housing.

MANUFACTURERS AND SUPPLIERS OF MODULAR UNITS IN PERMANENT BUILDINGS

Ayrshire Steel Framing
(a division of Ayrshire Metal Products Ltd)
Irvine, Ayrshire KA12 8PH

Tel: 01294 274171
Fax: 01294 275447

Britspace Modular Building Systems Ltd
Unicorn House, Broad Lane,
Gilberdyke, Brough,
East Yorkshire HU15 2TS

Tel: 01430 440673
Fax: 01430 441968

Terrapin Ltd
Bond Avenue, Bletchley
Milton Keynes MK1 1JJ

Tel: 01767 261313
Fax: 01767 262131

Volumetric Ltd
Rosedene House
12 King Street
Potton, Near Sandy
Bedfordshire SG19 2QT

Tel: 01767 261313
Fax: 01767 262131

Yorkon Ltd
New Lane
Huntington
York YO32 9PR

Tel: 01904 610990
Fax: 01904 610880

OTHER COMPANIES INVOLVED IN MODULAR CONSTRUCTION

R.B. Farquhar Manufacturing Ltd
Deveronside Works, Huntly,
Aberdeenshire AB54 4PS

Tel: 01466 79231
Fax: 01466 793098

Unite Group plc
33 Zetland Road, Redland,
Bristol BS6 7AH

Tel: 0117 907 8607
Fax: 0117 907 8632

Portakabin Ltd
New Lane
Huntington
York YO32 0PT

Tel: 01904 610990
Fax: 01904 610880

SUPPLIERS OF LIGHT STEEL FRAMING

Corus Framing
Whitehead Works,
Mendalgief Road,
Newport NP20 2NF

Tel: 01633 244000
Fax: 01633 211231

Metsec Framing
Broadwell Road
Oldbury, Warley,
West Midlands B69 4HE

Tel: 0121 552 1541
Fax: 0121 601 6126

Ayrshire Metal Products plc
17 Church Street, Irvine
Ayrshire KA12 8PH

Tel: 01294 274171
Fax: 01294 275447

Forge Llewellyn Limited
13.3.1 The Leathermarket
Weston Street
London SE1 3ER

Tel: 020 7357 7323
Fax: 020 7357 8157

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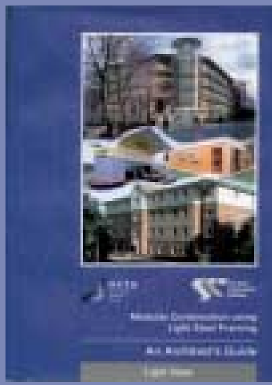

Modular Construction using Light Steel Framing: An Architects Guide (P272)

R M LAWSON, P J GRUBB, J PREWER & P J TREBILCOCK

This publication covers information required by clients, specifiers and architects when designing with modular units in residential buildings, in general building construction, and in renovation applications. It reviews the current uses of modular construction in the UK and in other countries, and gives technical information for use in design. Potential new uses are also covered. A list of manufacturers is provided.

Case Studies on Modular Steel Framing (P271)

R M LAWSON & P J TREBILCOCK

This publication consists of eight case studies covering the use of modular construction in residential buildings, in general building construction, and in renovation applications.

The Steel Construction Institute develops and promotes the effective use of steel in construction. It is an independent, membership based organisation.

The Steel Construction Institute

Silwood Park, Ascot, Berkshire SL5 7QN
Tel: 01344 623345 Fax: 01344 622944

http://www.steel-sci.org
e mail: reception@steel-sci.com