Building 15 February 2002

datafile

# Cost model

**How can prefabrication and ...ssembly deliver the buildings that clients and designers aspire to? In this cost model, ...s Langdon & Everest looks at case studies of recent applications of preassembly techniques**

## ...tion

...SE OF STANDARD, PREASSEMBLED COMPONENTS AND SYSTEMS ...any opportunities for a project team to increase the speed ...ty of construction, and in the longer term reduce overall costs. ...h prefabrication is being used on a growing number of projects, ...nstruction work is bespoke and site-based. Site-based ...ction suffers from low productivity, poor quality and uncertainty ... and programme, so preassembly gives the industry an opportunity ...te the step change needed to meet the Egan productivity targets. ...ication, in the form of modular construction, has been ...stically adopted by a select group of UK clients, including hotel ...pers and fast-food restaurant operators. At the other end of the ..., the use of preassembled components such as unitised cladding, ... wiring and so on has become well established in commercial ...cts that are otherwise assembled conventionally. The challenge on ... more typical projects is to extend the scope of prefabrication while ...elivering the flexibility and individuality that the client, project ... and site conditions demand. The take-up of this challenge has been ... to a small number of leading clients, such as BAA, and the social ...g sector where initiatives have been undertaken by the Amphion ...rtium and the Peabody Trust.

... the potential of prefabrication to be fully realised, the technology ...benefits of preassembly need to be better understood by clients and ... project teams. This would be easier if the makers made more design ... production information available to users. Projects also need to be ...igned and managed with the manufacturing and construction ...es in mind, entailing earlier decision-making and the closer ...ement of specialists. In the short to medium term, the project team ...eeds to consider the available capacity in the industry before ...tting a project to the preassembly route.

## Principles of preassembly

Before the potential benefits of preassembly are examined in detail, it is useful to understand the scope of the currently available prefabrication technology.

**Non-volumetric** These components include unitised cladding, prefabricated riser pipework and modular cabling systems. A particularly advanced example of a non-volumetric system is the panellised Tee-U-Tec technology used by social housing provider the Amphion Consortium. This year, Amphion is planning to build houses with timber frame panels that will incorporate prefinished windows and doors (see pictures).

**Volumetric** These are fully finished, non-loadbearing units that are ready for installation into independent frames. They are particularly suitable for highly serviced areas such as plant rooms or toilet pods installed into otherwise conventionally constructed buildings. According to research commissioned by manufacturer RB Farquar, the pod market will increase in value from £500m in 1999/2000 to £2bn by 2005, with most growth occurring in the residential sectors.

**Modular** These units provide the structure, and potentially the external envelope, of a building. Modular construction is particularly suited to cellular buildings such as student accommodation or stand-alone structures such as roof-level plant rooms. For the full benefits of a modular system to be secured, the work of designers and fabricators has to be co-ordinated, with the specialist being appointed early in the project cycle to provide design input.

**Above: Amphion has helped pioneer preassembly in social housing.**

The use of preassembled products may not always lead to a reduction in capital costs, but many of their other advantages have an indirect cost benefit that can outweigh an initial cost premium. A number of studies, including CIRIA's client guide to standardisation and preassembly, are being developed to facilitate the client's decision-making.

At the present level of technology, the key benefits of preassembly are as follows:

- **Certainty** Use of prefabricated components can significantly increase the client's confidence that project objectives will be met. For example, cost escalation can be controlled through an early design fix, a reduction in the scope of variations and the minimisation of rework on site. Programme certainty can be improved by transferring work away from site and by simplifying site operations, and quality assurance is increased by the use of factory assembly and through predelivery inspection.
- **Flexibility** In the long term, prefabrication will reduce the industry's dependence on a workforce that is forecast to contract, and so improve its capacity to respond to demand.
- **Cost** The potential for cost saving comes from the greater productivity and less waste achieved in factories compared with sites. Also, on large projects, economies of scale can be achieved: orders of 500 units attract a discount of 5-10%. These savings will be partially offset by transport costs and on smaller projects additional design, tooling and set-up costs. Indirect savings include reduced site supervision, simplified inspection, fewer variations and less reworking. Indirect benefits, such as early revenue streams related to a fast programme, also need to be factored in.
- **Time** Substantial programme savings can be made as on-site construction and off-site assembly can be programmed as parallel activities. Furthermore, simplified site operations and reduced requirements for inspection and testing will compress the programme. On the Peabody Trust's Murray Grove project in east London, which involved extensive site-based construction works, a programme saving of 18 weeks was achieved compared with a conventional project. This saved on interest payments and generated additional revenue through the early occupation of the flats.
- **Quality** Use of standard products, a multiskilled, stable workforce, factory conditions and off-site precommissioning should deliver quality far above that which can reasonably be expected from site work – as well as better conditions for the workers. Benefits include improved performance, better component fit and less movement and shrinkage in the completed building. To ensure defect-free construction, the prototype must be thoroughly tested in the factory before fabrication commences.
- **Productivity** Productivity can be increased at all stages of a project. Design time will be reduced when working with established systems, and factory-based assembly will be more productive than the equivalent works on site. Other areas of increased productivity include a reduction in the need for site management, inspection, waste and "shrinkage".
- **Profitability** Profit levels associated with the use of preassembly technologies are potentially higher, as a result of simpler and more dependable off-site and on-site processes. Higher profit provides opportunities for investment in research and development and areas of continuous improvement.
- **Standard components** The use of standard components results in a better fit between parts, reduces learning curves and increases the quality and consistency of the finished product. Although the use of standard products is at odds with the preference of many designers, it is often essential if fast off-site assembly programmes, which rely on the ready availability of materials, are to be met.
- **Safety** The transfer of work to a controlled factory environment increases safety, particularly by reducing the amount of work undertaken at height and the levels of congestion on site.
- **Environment** Working in factory conditions using tried and tested designs makes it easier to control waste and to increase recycling. Off-site prefabrication reduces the impact of construction work on neighbouring areas. On the debit side, off-site fabrication puts a greater reliance on road transportation, particularly for volumetric and modular buildings.

## How to procure preassembled products

The options available to clients that want to use preassembly are limited, and the range of specialists who undertake that work, particularly in the volumetric and modular sectors, is small. If you do procure a project that involves a high proportion of preassembled components, you should consider the following issues:

- The early appointment of specialist contractors
- The allocation of design responsibility between the specialists and the rest of the construction team
- The effective management of site works
- The encouragement of greater collaboration in the project team.

The early appointment of specialist contractors will need to be made on the basis of an assessment of quality and indicative price, as it is unlikely that fixed costs will be established until later in the programme. Quality criteria should include a technology assessment, consideration of available capacity and the deliverability of the proposed system. The preferred specialist could be appointed as an adviser during the early stages of the project, so establishing a duty of care to client. Alternatively, the design proposals could be worked up at an early stage to a point where a firm price could be agreed and a contract put in place.

The issues of the management of works and the allocation of responsibility are inseparable. On projects with a small proportion of preassembled work (just toilet pods, for example) the work can be managed as a specialist trade contract. However, on projects with a higher proportion of preassembly work, the organisation of appropriately experienced site management can be more problematic. In most cases, specialists have neither the capability for, or interest in, taking on the full responsibility and financial exposure associated with the entire management of a project. However, the employment of a main contractor may involve a duplication of resources, plus the risk of having the site managed by someone with limited experience of preassembled systems.

The principal procurement options available to the client are a lump sum or a package contract. On lump projects, there will be a single point of contact and responsibility for the co-ordination of the works, which will transfer risk away from the employer. This provision is useful when, for example, tolerance issues or delays in the completion of groundworks affect the installation of the modules. On the other hand, communication between the design team and the specialist may be impeded, a problem that can be alleviated by partnering. When making an appointment on capacity, the assessment should focus on the contractor's ability to deliver modular projects at a fast rate, as well as cost and other criteria.

On construction-managed package projects, the employer will be able to select preferred contractors for each package and to clearly allocate responsibilities for items such as site set-up, craneage and so on. This approach should facilitate better co-ordination between individual contractors, but the client's involvement and risk exposure will increase. Issues associated with warranties and other performance guarantees will also be more complex, where, for example, the interface between the module and a separately installed external envelope are involved.

In summary, the success of the lump sum route depends upon the involvement of main contractors with a positive belief and successful record in delivery of preassembly schemes. Following the package route gives the client more control and the specialist a more prominent role in the process at the expense of some transfer of risk to the employer.


components are unloaded directly into position.

## Toilet pods in a City of London office

project involves the installation of 91 dual toilet and washbasin pods in otherwise conventional new-build -frame office building. The project is of the first uses of toilet pods in the since the early 1990s. Internal finishes of high quality and include granite, slate glass.

### Objectives

pods were chosen by the client, which used them on developments elsewhere Europe. Its objectives were:

- hievement of high levels of quality
- Simplification of the on-site programme
- Risk reduction
- Maintaining "as built" quality by keeping locked until completion.

### Procurement

The project is let on a construction management basis. Tenders for the pods were obtained well in advance of the site installation programme. The three standard modules designed for the scheme were completely bespoke, based on a concrete frame.

### Cost and programme

Category A 15,600 m² office development, costing £28m
Total cost of the toilet pod package: £620,000
Average cost per pod: £6,800
The on-site installation, excluding services connections, took four weeks, compared with the 18 weeks that conventional construction would require.

### Project outcome

- The pods were installed on programme.
- The quality of finish is high.
- Problems with district surveyor approval have resulted in some rework on site.

### Main points

- Importance of the client's commitment to the use of prefabricated pods.
- Access to services once installed should have been considered in more detail during design.
- Very detailed testing and inspection of the prototype is required to ensure that all potential problems are identified before production.

Support for floor cassette on Amphion social ho

## Case study two: Modular student residences

The scheme was to construct a 750-bed student residence on a brownfield site using prefabricated bedroom, kitchen and staircase modules. The completed building is to be clad in a terracotta rainscreen with a pitched roof to meet the planners' requirements.

### Objectives

The main reason that modular construction was used was to ensure certainty of completion for the start of the academic year. The use of modules will make this large scheme feasible by compressing the programme and simplifying the completion and handover of large numbers of rooms.

Secondary development objectives included:

- Avoidance of delay
- Cost certainty
- Achievement of high-quality construction at a reasonable cost.

### Procurement

The project is to be let on a package basis, with site preparation, civils and groundworks, modules, cladding and external works being let as four separate sequential trade contracts. Module specialists were interviewed during RIBA stage B, with the appointment programmed to be finalised before outline planning approval is obtained. Overall project co-ordination will be provided by the client's project manager. The modules will be designed to suit the specialist's standard layout.

### Cost and programme

A two-phase programme is proposed, with units being released six and 18 months after the commencement of the main building programme. The main building works will be preceded by a separate site preparation and infrastructure contract (see table).

### Main points

- The potential for significant savings associated with economies of scale and through the adoption of the module manufacturer's standard dimensions.
- Choosing the right specialists with good available capacity at an early project stage.
- The need for a flexible approach to procurement to ensure that the client's objectives are met.

## Student accommodation

| | Element cost £ | |
|---|---|---|
| **Substructure** | 1640 | 72.2 |
| Piling, deep strip foundations and ground-bearing slab; reduced level dig, disposal | | |
| item @ 1,229,000 | | |
| **Modules** | 13,210 | 582.7 |
| Bedroom modules, fully furnished, complete with en-suite bathroom, including all se | | |
| connections with below-ground installation | | |
| 750 @ 10,500 | | |
| Kitchen modules, fully fitted, including all services to final connections with below-gr | | |
| installation | | |
| 125 @ 13,500 | | |
| Stair modules | | |
| 30 @ 11,500 | | |
| **Envelope** | 4130 | 182.2 |
| External walls – terracotta rainscreen; including allowances for framing and interfaces | | |
| 17,000 m² @ 140 | | |
| Roof – timber structure, roof tiles, rainwater goods | | |
| 6250 m² @ 115 | | |
| **Joinery generally** | 190 | 8.2 |
| Internal and external doors, canopies | | |
| item @ 140,000 | | |
| **Finishes generally** | 1520 | 66.9 |
| Wall, floor and ceiling finishes to corridors only | | |
| item @ 88,000 | | |
| **Ancillary buildings** | 1400 | 61.77 |
| Allowance for conventionally constructed amenities buildings | | |
| item @ 1,050,000 | | |
| **Contingencies** | 620 | 27.35 |
| Allowance based on 3% | | |
| item @ 465,000 | | |
| **Total construction cost – building only** | 22,710 | 1001.5 |

Reported costs are current in 1st quarter 2002, based on a location in south-east Engla Preliminaries are included in the rates. The costs exclude site remediation costs, infras external works, professional fees and VAT

## Amphion panellised social housing

...rtium of 20 housing associations has pooled some of their ...ment programme to provide volume for the factory production ...tech timber dwellings. These have been designed to take ... of the Egan principles, and to meet planned Building ... changes until 2010. The featured project is a 35-dwelling ... in southern England. Amphion Consortium dwellings are ... on a proprietary timber-framed wall technology developed by ...ships First, which aims to eliminate buildability problems and ... fabric performance in areas such as insulation, air infiltration, ... and so on.

### Objectives

- ... workload of separate clients to provide volume to ... the continuing development of a preassembly technology
- ... lean production techniques based on sustainable ... and to reduce waste on site
- ...crease quality and productivity and to achieve sustained ... in construction cost based on an agreed programme of ...logical improvements
- ...crease cost and time predictability
- ...achieve reductions in reportable accidents.

### Procurement

...assembly specialist, Partnerships First, has been appointed in a ...ing agreement. Partnerships First was selected largely on the ... of quality criteria, although construction costs were considered ... the second stage of tender, and were given a weighting of 25% ... final quality/cost assessment.

...ing negotiation of the partnering agreement, an open-book ... mechanism was agreed, based on known preliminaries, ...heads and profits. Although early projects were let on an amended ... With Contractors' Design form, most projects are currently ... on the basis of the partnering contract, PPC2000.

### Construction costs

... table opposite sets out the costs of the scheme. The building-only ... for this relatively large scheme of 35 units is £569/m², which ...pares with the mid-range of social housing costs from the ... database of £570/m² to £645/m². Currently, the cost of the ...fabricated components is 21% of the superstructure costs. The ...-term aim is to increase this value to 75%.

### Project outcomes

- ...date, more than 100 units on different sites have been completed ... Amphion technology, and a further 360 are in contract.
- ...cipated levels of demand have not yet been reached, which has ...ected the contractor's performance.
- The management buyout of Partnerships First, following a hostile ...over of its parent company, directly affected the project during ... early stages
- Technology improvements have resulted in reductions of 5% in ... costs of the timber-frame panel kit, plus faster installation
- A programme of technology improvement, which will initially ... the addition of factory-finished and fitted windows and ..., has the potential to deliver significant benefits to the client
- Contractor performance on some projects has been below ...pectations.

### Main points

- The importance of the consortium's commitment to the ...gramme – in terms of providing volume of work and the drive ... continuing improvement
- The benefit of partnering with an agreed pricing framework
- The sensitivity of the consortium to initial capital costs
- The benefits of commencing with a relatively low level of ...fabrication when combined with a continuous improvement ...gramme (improvements occur in steps rather than as a smooth ...gression, and the pace of change can initially be slow)
- The importance of ensuring that the specialist has adequate ...ality control resources.

### Amphion project

| | | | |
|---|---|---|---|
| **Substructure** | 4500 | 53.29 | 9.37 |
| Strip foundations and ground bearing slab; reduced level dig, disposal<br>item @ 162,000 | | | |
| **Frame, upper floors and partitions** | 9110 | 107.93 | 18.97 |
| Timber frame panels, external wall panels, upper floors, roof structure and internal partitions<br>item @ 328,100 | | | |
| **Roof** | 2840 | 33.65 | 5.91 |
| Roof coverings; concrete roof tiles, rainwater goods<br>item @ 102,300 | | | |
| **External wall cladding** | 5630 | 66.71 | 11.73 |
| Single skin outer brick wall<br>item @ 202,800 | | | |
| **Joinery generally** | 6560 | 77.73 | 13.66 |
| Stairs<br>item @ 36,200<br>Windows and external doors; timber; site finished<br>item @ 150,100<br>Internal doors<br>item @ 50,000 | | | |
| **Finishes generally** | 8910 | 105.49 | 18.54 |
| Wall, floor and ceiling finishes<br>item @ 320,700 | | | |
| **Furniture and fittings** | 1540 | 18.19 | 3.20 |
| Fixtures and fittings generally<br>item @ 55,300 | | | |
| **Services generally** | 8940 | 105.92 | 18.62 |
| Sanitary fittings<br>item @ 33,800<br>Plumbing<br>item @ 89,800<br>Heating and ventilation<br>item @ 126,500<br>Electrical installation<br>item @ 71,900 | | | |
| **Total construction cost – building only** | 48,030 | 568.91 | 100 |
| **External works** | 11,140 | 131.91 | – |
| Drainage, service trenches, lighting, drives, parking areas and paved areas, soft landscape, screen walls and fencing<br>item @ 401,000 | | | |
| **Adoptable works** | 6970 | 82.57 | – |
| Roads, footpaths, sewers, street lighting and street furniture<br>item @ 251,000 | | | |
| **Service mains and connections** | 3830 | 45.39 | – |
| item @ 138,000 | | | |
| **Overall construction cost** | 69,970 | 828.78 | – |

Reported costs are current in 1st quarter 2002, based on a location in southern England. Allowances for preliminaries and contingencies are included in the rates. The costs exclude site preparation costs, off-site works including services diversions, surveys, professional fees and VAT

**Kitchen wall panel with pre-cut hole for boiler flue.**

## Addressing problems with preassembly

The client and the project team need to address the following key points if they are to get the full benefits of prefabrication.

■ Developing a knowledge of preassembly applications means:
Awareness of the latest technological developments.
Appreciation of the need to balance the benefits of standard solutions with the client's need for a bespoke design solution.
Recognition of the benefits of incorporating a high proportion of finishes and other works into the preassembled element of the project.
Need for the project team and contractor to be committed to the idea of preassembly.
Appreciation of the risks involved in selecting an inappropriate preassembly solution.

■ Achieving a continuity of workload to provide economies of scale and to support investment in continuous improvement.

■ Need for planning to secure benefits. Careful planning is required at an early stage on preassembly projects. Important areas for planning include the timing of securing input from the specialist, setting timescales for the appointment of the specialist and for the freezing of design, and the sequencing of on- and off-site works. It is vital that the programme allows sufficient time for design and preplanning activities.

■ Dealing with the planning authorities. Planners' preference for traditional materials on projects commonly results in hybrid schemes with a traditional envelope construction – affecting both cost and programme.

■ Working within the constraints of module sizes. The project team's understanding of, and adherence to, standard sizes will simplify production and keep costs down. For example, the Amphion Consortium use a set of standard house types to optimise the performance of its timber panel system.

■ Selecting materials to meet the accelerated production programme. Besides the sectors where prefabrication is commonly used, such as modular and hotel bedrooms, toilet pods and fast food restaurants, there are few established supply chains. In the absence of these, selection of finishes and other materials will be influenced by the need to ensure availability. The ability of material suppliers to meet accelerated programmes should be a key element of selection.

■ Interfaces with conventional construction. There are a number of potential difficulties in combining the two methods of construction.
**Tolerances** Foundations, cladding, drainage and so on will need to be constructed to much finer tolerances to match the accuracy and to accommodate the reduced dimensional flexibility associated with preassembled systems.
**Lack of flexibility** As a result of the early design freeze of the preassembly process, there may be less flexibility available down the line in designing and constructing the site works than there would be on a conventional project.
**Contractual interfaces** Many preassembly specialists do not have the project management skills and commercial clout to take control over all elements of a construction project. In these circumstances, more complex procurement routes will be necessary to ensure the co-ordination of the construction packages and issues such as warranties.