Prefabrication in house constructions

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Abstract This paper examines the development and current status of prefabrication techniques and their application in building construction. An overview of the current UK house building market and its status in terms of the utilization of prefabrication techniques has been made. Investigation of past engineering practices and existing knowledge of prefabrication has allowed several low cost techniques to be summarised. These would minimise the initial investment required to adopt prefabrication and so increase its market potential for UK house construction. Finally, a summary of the review work is provided.

Keywords Prefabrication; component; module; house; construction

1. Introduction

Prefabrication using large panel technology, first developed in the mid 1960s [1], allows relatively rapid construction of large numbers of buildings at moderate unit cost. The popularity of this method stems mainly from the cost savings provided by mass production of standardised building elements and the reduction of labour costs on-site. Prefabrication may be considered for whole buildings or for discrete components. For example, prefabricated components could include walls, floors, roofs, closet shelving/interiors or kitchen cupboards.

It is important to note that additional costs may be incurred by the use of prefabrication methods. These may include the cost of shipping and handling, for example, particular care is needed when handling large concrete slabs. Extra reinforcement, care and precautions may be required to ensure the concrete slabs do not fracture or crack and joints are not stressed.

The advantages of using prefabrication techniques in term of availability of materials, labour and technical skills are as follows [2, 3, 4, 5]:

- Off site manufacture of components with more efficient use of skilled labour, materials and specialised plant and equipment under controlled conditions offering components that are of a high standard.
- Accelerated erection on site.
- Market for new components resulting from envelope upgrades or spatial reconfiguration.
- Market in second hand components resulting from changes to dwellings or disposal of dwellings.
- Potential for relocation of dwellings rather than demolition.
- Minimal use of in-situ materials minimises waste on site and at the end of the building's useful life. This reduces the manufacturer's liability for disposal.
- Self-supporting, shuttering and scaffolding is eliminated with a saving in shuttering cost, as the components are made ready.

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- Mass production of building components results in increased productivity and savings per unit cost.
- Building components are factory-made, which avoid any adverse effects due to poor weather conditions.
- Possibility of implementing renewable energy devices in building façades as well as use of low cost sustainable materials.

The future of the UK construction industry will depend on its ability to embrace new cost-efficient technologies and systems, innovative housing technology, and measures to improve sustainability in line with emerging legislation. Prefabrication techniques are well suited to these ideas, and the catalogue home could create a concept in flexible, customised design [6].

2. Concepts of prefabrication

Prefabrication is the production of housing or housing components using factory mechanisation. The factory setting enhances affordability through a combination of bulk purchase of materials, mass production assembly techniques and the use of less skilled labour. Prefabrication can take one of three forms: prefabricated components, modular housing, and manufactured housing [7].

The prefabrication of housing components, such as windows, doors, and cabinets, has long been a mainstay of the construction industry, keeping costs down by reducing on-site, high- cost labour. Continuing development in this facet of prefabrication provides a growing range of construction products that may further reduce construction costs.

Modular housing involves the prefabrication of sections of housing that are then assembled on-site thereby reducing on-site labour costs. Modular housing is based on prefabricated, factory-produced, easy-to-transport modular units, which minimize the cost of production. Final structures are designed from the inside out using a series of standard "modules of use" and dwellings composed of these modules have the potential to be configured in a variety of ways, according to the specific requirement of the site or client [8].

3. UK house-builder market

In recent years, new housing has been one of the leading sectors of the UK construction industry, contributing just over 30% in terms of output value. In 2003, output in the overall housing sector stood at over £15 billion. Of new housing work, private sector output showed an increase during 2003 of 27%, with public sector housing also rising but at a lower rate of 17% [9].

To avoid a future housing shortage, around 200,000 homes will be required in London and the South East by 2016 [9]. For long-term stability and to slow house-price inflation, an increase in house supply of between 70,000 and 120,000 extra homes per year across the UK will be required [9]. Funding allocated by the government in its Sustainable Community Plan is available to support this housing development.

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There are around 20 quoted house builders in the UK with a market capitalisation of between £20 million and £15 billion. The largest by volume is Barratt Developments with 7.8% of the market, closely followed by George Wimpey and Persimmon with 7.6% and 7.2% respectively. These three firms continue to dominate in terms of unit completions and in 2003 together accounted for an estimated 22% of the market [9].

4. Prefabrication in UK house construction

Prefabrication techniques are widely used in America, Germany, Scandinavia and Japan [10]. In Japan almost all housing is factory built but in the UK and Australia its application is still fairly limited.

The UK market for prefabricated buildings has grown over recent years. During the period 1996–2003, the market experienced annual growth of around 1–8%, reflecting varying levels of activity in construction sectors. In 2003, the total market was £512 million at manufacturers' selling prices, which represented growth of around 9% compared with the previous year. In 2004, substantial growth of around 10–11% occurred in the overall market. From 2005 to 2007, the overall market is forecast to continue to grow at a rate of around 10–11% per annum, reflecting growth in a range of end use sectors, increasing government expenditure, and expansion in concrete, steel frame and pods including volume production for accommodation blocks and prisons. Growing penetration in the house building sector may also provide some additional motivation in the medium term and this represents an area of opportunity for prefabrication and off-site manufacturing in general. Furthermore, market penetration continues to be facilitated by PFI and PPP, which is underpinning capital expenditure in the public sector [11].

The UK has achieved a capacity that allows a production of around 30,000 homes per annum. However, this figure is still well short of the capacity needed to meet official house projections. The Government is therefore promoting pre-fabrication techniques, looking to methods such as steel and timber frame and modular construction to address the housing shortfall.

Off-site construction currently accounts for just 3% of house-building, and the House Builders Federation is calling for government subsidies to encourage housebuilders to adopt prefabrication methods and to justify the investment required. The Government committed to providing 4000 off-site homes for the social housing sector in 2003/04 with an investment of £250m, with further investment in 2004/5.

Prefabrication in concrete, steel and timber has been facilitated by regulatory and innovative influences, particularly in the steel frame sector where the continuing underlying technology support and product development of Corus has played a significant role in propelling the metal sector into greater prominence [11]. Innovative influences are also motivating timber frame and concrete construction. Many timber house components can be mass produced and the scope of concrete precasting and cladding options has been broadened significantly, e.g., Baggeridge's Corium and Kingspan's Kingframe.

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The market can be segmented by type of building, and by type of end user. The term 'volumetric' refers to off-site completed units, pods or modules, and the term 'semi-finished' refers to partially assembled units, pods or modules requiring a greater degree of assembly on site. Both 'volumetric' and 'semi-finished' include pre-cast concrete, steel frame and timber. The majority of prefabricated buildings, including steel cabins, accommodation and storage units, are of the volumetric type, with a market share of around 65% by value, whilst semi-finished have a share of around 35%.

End user sectors comprise commercial and industrial, hotels, educational, residential, healthcare, hire, defence, and the infrastructure including asylum centres, immigrant detention centres, prisons and community facilities. Forecasts indicate varying levels of growth in these sectors dependent on end-user market growth and the likelihood of share gain from traditional building where the scarcity of skilled personnel will be accentuated by recent increases in government funding, notably sectors such as social housing, health, education, and infrastructure. Product innovation also influences sector growth prospects with Corus' blast resistant structure representing a significant technical advance with the potential of wide application.

Several niche growth sectors have been identified. These include the growth of the security sector, (for example, explosion resistant buildings), modular accommodation, private houses, self-contained cabins, and 'welfare' units, power units, etc. It is likely that volumetric and semi-finished production will be used increasingly in the private housing market as a result of prefabrication developments including a wider choice and selection of prefabricated houses, and the impact of large production resources emanating from Framing Solutions, Space 4, etc. Levels of productivity are improving in the masonry sector owing to the application of production engineering techniques, standardisation, and fabrication of components and subassemblies as part of the move to prefabrication by house builders and suppliers [11].

The prefabricated building industry has become increasingly fragmented as many companies recognise the growth prospects of prefabrication. In 2003, the overall market leader was the Shepherd Building Group, which has four subsidiaries Portakabin, Portasilo, Yorkon, and Foreman, and has a collective share of around 20%. Elliott Group is estimated to account for a 15% share followed by Atlas Ward, Cosalt and GB Industries each with a 6–9% share. GB Industries (formerly Horncastle Industries) includes Britspace, Gateway Fabrications and Ultra Secure Products. It is estimated that market shares of 2–5% are held by CV Buchan, Compton, RB Farquhar, Rollalong, Terrapin, Thurston, Tingdene, Premier Transline, Precast Cellular Structures, Wernick, Caledonian Building Systems. Other companies involved with prefabrication include Kingspan Metl-Con, SGB Rovacabin, Volumetric, McAvoy Group, Bell and Webster and Bison [11].

In addition, Westbury have a substantial in-house prefabrication capability – Space 4, whilst Unite operate an in-house prefabricated facility including mass-produced pods for student accommodation blocks.

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5. Low cost prefabrication techniques

5.1 Prefabricated components

Prefabrication of windows, doors, kitchen cabinets, and roof trusses has long had a place in home construction. Recent innovations have resulted in an even wider variety of prefabricated components, which increase affordability. The following are descriptions of some of these innovations and how they enhance affordability.

Walls and roofing

There are many materials which may be used for the construction of walls. These include rammed earth, conventional bricks, soil cement blocks, hollow clay blocks, dense concrete blocks, and modular panels of various sizes. Although bricks are still the backbone of the building industry, large size panels made of low-density materials have increasingly been used for the construction of modular walls. The size of the panels depends on client requirements and the material used for construction. These materials include industrial wastes, such as blast furnace slag and fly ash, or a sustainable medium such as straw. This technology is economical in comparison with traditional brick wall construction due to greater speed of construction and lower mortar consumption [2].

Prefabricated panels framed with wood or light-weight steel framing clad in a range of exterior and interior finishes can be used for exterior walls. The wall assembly usually contains insulation, wiring, and pre-cut openings for windows and doors. Costs are reduced as a result of a reduction in on-site labour. A "panelised home" uses factory-made panels that include whole walls with windows, doors, wiring or outside siding [7]. The components are brought to the site to be erected or assembled as required.

Structural floors/roofs account for a substantial cost of most buildings. Therefore, any savings achieved in floor/roof construction considerably reduce the cost of the building. A traditional cast-in-situ concrete roof involves the use of temporary shuttering which adds to the cost of construction and time. Use of standardised and optimised roofing components where shuttering is avoided has been shown to be economical, fast and of higher quality.

Some prefabricated roofing/flooring components found to be suitable in low-cost housing projects are precast RC planks, precast hollow concrete panels, precast RB panels, precast RB curved panels, precast concrete/ferrocement panels and precast RC channel units [2].

In recent years, Structural Insulated Panels (SIPs) have become the most common form of prefabricated building envelope system [7]. SIP's are composed of two exterior skins (such as oriented strand board, waferboard, plywood or gypsum board) adhered to a rigid plastic insulating foam core (usually polystyrene). Panels are available in a variety of thicknesses, depending upon the requirements and size. Their primary application is for exterior walls and roofs with conventional wood or steel stud framing for interior partitions. SIPs form a solid thermal envelope around the structure, uninterrupted by studs, sills or headers. This eliminates gaps found in normal insulation and can reduce heating and cooling costs by approximately 15%

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over conventional site-built homes [7]. While the cost of a SIP house may be greater for materials, the shortened construction period and superior energy performance contribute to cost savings in both the short and long term.

Roof panels, such as those made of Oriented Strand Board (OSB) have a short construction time and are uniformly sound and extra rigid to handle snow and wind loads. Roof panel systems can decrease the amount of labour required to roof a building by 30% to 40% [7].

Room kits

Bathrooms and kitchens traditionally have the highest per square foot costs in residential construction. Room kits are now being produced which contain all the components of these rooms, including cabinets, wall flashing, and all the requisite wiring and plumbing ready for hook-up [7]. As in the case of modular housing, computer design plays a large part in providing the dimensional accuracy needed for such "pop up" modules. These kits may be shipped as a complete unit, which is lowered into place, or in pre-cut sections. A study carried out in Australia has shown that this application of prefabrication can provide a cost saving of 15% over in-situ construction of these areas, with a project time saving of 13% [7].

5.2 Modular Housing

A modular house is highly engineered. It is constructed in sections and put together by a builder on the site. Modular houses are designed, engineered and built in a factory-controlled environment. Most modular producers use state of the art computer aided design programs. Speed of construction and consistent quality are two of the major advantages of modular housing. For example, a house consisting of two sections can be built in the factory in a couple of weeks. Once the manufacturing is completed, the sections are transported to the housing site where they are placed on the foundations. Final completion is handled by a local builder or general contractor who connects utilities and carries out finishing work. This process usually takes another two to three weeks [7].

Factory-based mass production is a way of reducing the cost of module houses. Computerized Numerically Controlled (CNC) machines, already in use in large millwork and metal plants, allow for custom parts to be produced as fast as identical ones. If this technology were applied to the residential-construction market, the cost of prefabrication would be reduced significantly. New materials, such as polymers, composites, and special-purpose metals could also be considered for residential use [8].

5.3 Manufactured housing

Manufactured housing is fully built in the factory and today's structures are virtually indistinguishable from their site-built counterpart. Entire houses, containing the same amenities as site built homes, are shipped to the site and placed on a permanent foundation. Manufactured housing is durable, desirable and a viable form of affordable housing.

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The per square foot construction costs of manufactured housing at the factory are less than half that of a site-built house – $27.83 per square foot compared to $58.11 per square foot excluding land (1996 US figures). Manufactured houses do, however, encounter site installation costs typically of about $8000 (US), but still remain much cheaper than site-built dwellings. Although savings may vary from one region to another, manufactured housing costs approximately 35% less than conventionally constructed housing [7].

The use of land leases in communities using manufactured housing also improves affordability. In 1996, about one third of all new purchasers of manufactured homes in the US chose land leases. Particularly common in retirement communities, land lease tenure greatly reduces the cost of manufactured housing because the land is "rented" from the owner or management firm of the housing park. Significantly less start up capital is required by the household to obtain this type of housing [7].

Manufactured housing is becoming popular in Canada especially in the Maritimes and in some high growth areas in the West. This popularity is a result of its affordability. In Alberta, an annual income of $27,000 is required to afford a 1200 square foot manufactured home, but $47,500 to afford a 1200 square foot site-built home. In Nova Scotia an annual income of $24,000 is required to afford a manufactured home, but $36,000 for a site-built home [7].

A municipality that has used manufactured housing on a large scale is the City of Fredericton, New Brunswick, Canada, where in 1988, a 50-acre subdivision provided 325 lots for manufactured homes. By 1993, 180 homes had been completed and these sold for $75,000 to $90,000 ($20,000 to $30,000 less than similar site-built homes) [7].

In the United States, it is estimated that approximately 18 million people live full-time in 8 million manufactured homes (1995 figures). Approximately 15% of all occupied housing units in the US are manufactured housing. Manufactured housing accounts for one quarter of all new homes in the US sold and is the primary source of unsubsidized affordable housing [7].

Conclusions

In recent years, prefabrication has been widely used in the building market worldwide, particularly in American, Germany, Scandinavia and Japan. Use of the prefabrication techniques in UK house building is still lower, but the rate of growth for application is significant. The key issue for promoting prefabrication is to seek for potential low cost techniques, including using sustainable/recycled materials, such as rammed earth, blast furnace slag, fly ash, or straw, increasing the size and reducing the number of the components used, use of modular design of house components, factory based mass production, advanced machinery technique, as well as intelligent computer aided design. The review work carried out by the authors will assist the development of prefabrication techniques, and therefore, aid to promote their applications in the UK market.

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