The future for **precast concrete** in low-rise housing

Dr. Jacqueline Glass

The Future for Precast Concrete in Low-Rise Housing

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About this report

Much has been written in the trade press and in research papers regarding the potential for prefabricated and off-site methods of manufacture to bring both increased speed and enhanced quality to UK construction projects. The Department of the Environment Transport and the Regions (DETR) and the precast concrete industry have noted this interest and have been pro-active in seeking to establish the true extent of this trade and public interest in factory production techniques. These techniques have been supported by Sir John Egan's 'Rethinking Construction' report as the way forward for improving quality and speed of construction.

House building in the UK is a major industry but much potential exists to further develop the design, construction, procurement and aftercare of new build homes. The basic construction technology used relies mainly on traditional skills and materials; these are still used in the majority of new housing projects. Although the construction industry has previously been known for its tardiness in adopting new techniques, there is renewed interest in assessing the scope for prefabrication and industrialised building techniques.

It is with this background that the Precast Housing Feasibility Study Group was established in March 1999 to review the use of precast concrete in the low-rise domestic housing market, as individual components or as integrated modular forms of construction. The findings of the Precast Housing Feasibility Study Group are presented in this publication which aims to assess the feasibility of using precast concrete elements to build cost effective and aesthetically pleasing low-rise dwellings that meet occupiers' expectations and comply with the Building Regulations.

'Only manufacture in controlled factory conditions can achieve the defect free, waste free quality production on budget, on time, that clients and consumers deserve. And only factory conditions are likely to provide the sort of safe, healthy, pleasant working environment that will be acceptable to the young talented, skilled workforce that the industry needs'.

Nick Raynsford, Minister for Construction and Housing October 1999 opening the Peabody Trust's volumetric housing project at Murray Grove, Hackney.

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Executive Summary

This report is about the future use of precast concrete in low-rise housing in the UK. It has been produced in response to a growing level of interest in prefabrication. The report is in four parts.

Part One focuses on the use of precast concrete, and considers the history of precast concrete in housing, including the Ronan Point incident. Clearly there is an argument that precast concrete has a (historical) reputation which to some extent continues to prejudice its use in housing. Reference is made to the current market for precast products. The portfolio of products available both in the UK and elsewhere are outlined, and an explanation of the basic types of precast concrete used in housing is also given. The examples of precast concrete from other EC countries show that there is market potential for the product in housing provided manufacturers promote sensible options to a well-informed market. There are clearly lessons to be learned from countries that use a higher proportion of industrialised housing than the UK.

Part Two examines the key features of concrete in general, and precast concrete specifically. Fire resistance, thermal mass, acoustic insulation and durability are included together with a discussion of cost and value issues. Indeed, take-up of precast may ultimately depend on the balance of construction costs and added value. This difficult equation may need to be resolved on an individual project basis, thereby offering every house building client a bespoke package. For precast concrete to make inroads in the housing market, contractors and clients need to be made aware of the speed and quality benefits it offers, while owners and occupiers need to be made aware of the performance benefits over time such as thermal mass. Other considerations such as services integration and adaptability are related to the future needs of occupants, and procurement strategies are noted.

Precast hollowcore panels being installed on site (courtesy of Tarmac Topfloor Ltd)

Part Three focuses on the broader issues that could affect the take-up of precast in housing. The findings from recent surveys of the public, house builders and housing associations are presented. There is a body of opinion that supports the notion that traditional materials are the most appropriate and popular for new housing in the UK, but there is also a growing interest in different styles and ways of living, particular in urban areas. The surveys presented here suggest that the UK continues to prefer heavyweight construction. A discussion of the influence of other market drivers is given; the Egan report and sustainability could have significant impact on the way in which all housing is procured in the future. This Part of the report also contains an account of the current market success of other materials in the prefabricated housing sector. Although steel and timber are being used, recent surveys indicate that the public seems not to be particularly keen on prefabricated buildings in general.

Part Four includes conclusions and recommendations. The seven key findings from the report are stated, together with brief case study accounts of a number of future precast housing projects. The findings are that:

1. The problems of the past can be avoided
2. Low-rise is not high rise
3. Cultural and perceptual views are critical
4. The market potential for precast concrete exists
5. The balance of cost and value needs to be clear
6. Precast means innovation in delivery
7. People need to be convinced

A series of recommendations are made which are relevant to the DETR, precast manufacturers, designers and contractors in addition to the house building industry at large. These include the call for a series of seminars for the industry, a demonstration building and a range of further R&D activities.

Part 1 - Precast Concrete in Housing

1.1. Introduction

This first part of the report gives a general introduction to the subject and a historical review of precast concrete in housing which charts the progress of concrete through the 'system' building era and beyond (1.3). Current techniques and patterns of use are described in section 1.4, and can be read in conjunction with relevant market statistics in 1.5. Reference is also made to the use of precast in other countries such as Germany, the Netherlands and Japan (1.6).

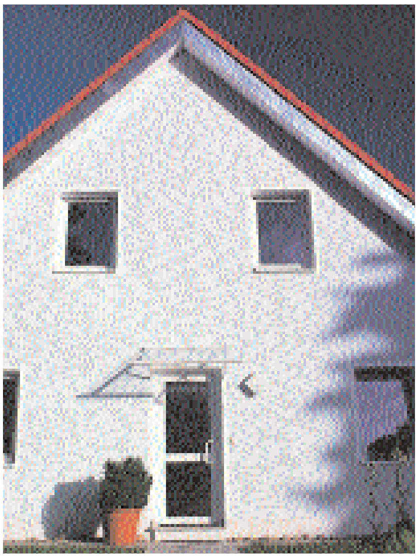
1.2. Scope of this Report

The scope of this publication is limited to the use of precast concrete for low-rise housing. In some instances, reference is also made to related concrete technologies and other markets for which this report may be also be useful. This report refers to a wide range of precast concrete products. However, the focus is on concrete components, elements or modules that are manufactured off-site and then assembled on-site at a later date (Russell, 1991). This includes mainly structural elements such as walls, beams, floors, columns and panels. For the purposes of the report, other small-scale precast products such as concrete blocks and lintels have not been included. Reference is made to:

- Open systems (elements which are compatible with other building components)
- Closed systems (elements which are compatible only with each other)

In particular, the text refers to components, panels (two-dimensional) and volumetric (three-dimensional) applications for precast concrete.

The term housing encompasses single homes, sheltered housing, student accommodation, motels and hotels etc. This report, however, considers dwellings ahead of commercial buildings. The two key markets considered are individual homes and apartments in public and private sector developments. The use of the term 'low-rise' here is intended to cover dwelling types up to four storeys in height, including private rented and sale sectors of both speculative builders and housing associations/trusts. Clearly each of these markets is quite different and requires different functionality, planning and aesthetic provision; where appropriate these factors are taken into consideration. It should be noted that regional variations in take-up, architectural style and uses are also relevant.



Contemporary Precast concrete homes in Germany - The 'Icon House' (courtesy of Veit Dennert KG)

1.3. Historical Review of Precast Concrete in Housing

The history of precast concrete in UK housing dates from the mid 1900's, when this and other forms of industrialised (prefabricated) construction were used to address the problem of widespread destruction of housing stock during the Second World War. More than 250 precast concrete 'systems' have been acknowledged, but less than 100 were deemed to be sufficiently robust or durable to warrant further commercial development. These included a tranche of 'closed' systems i.e. those constructed from a set of integrated components designed to work together, such as Airey, Boot, Dorran, Myton, Newland, Orlit, Parkinson, Reema, Shindler / Hawkesley, Stent, Tarran, Underdown, Unity, Wates, Whitson-Fairhurst, Winget and Woolaway. Although by the 1950's the high demand for new housing had reached a plateau, in the early 1960's another further, sudden increase in demand meant that precast concrete systems were used yet again as a replacement for other unfeasibly labour-intensive conventional construction methods.

Past precast: The 'Woolaway' bungalow UK, circa 1960

By 1960, over 165,000 precast concrete dwellings had been built, ranging from small single storey bungalows to large high rise (multi-storey) blocks. However, the design and production facilities used in previous decades had all but disappeared. As a result, other systems were 'imported' from Europe and elsewhere, only some of which were modified successfully to comply fully with UK construction practice and environmental conditions. These imported housing systems were used mainly for the construction of high-rise buildings and included Spectra, Camus and Tracoba from France, and Jesperson from Denmark. Of these, the so-called LPS (large panel system) construction, used mainly for high-rise buildings, suffered a major setback in the Ronan Point collapse in 1968 caused by a gas explosion in a block of flats in East London.

It was discovered at a subsequent enquiry that this type of building was susceptible to progressive collapse, resulting from a lack of structural continuity at the joints of the various precast components (it was not designed to resist disproportionate collapse). In following years, a comprehensive review of similar systems resulted in strengthening and/or demolition of vulnerable properties.

After the Ronan Point incident, a Building Regulations document was introduced for all buildings with five or more storeys and guidance was given for reducing sensitivity of the building to disproportionate collapse in the event of an accident. During the past thirty years or so, the guidance has been improved, but not changed substantially in principle, and it features suitably in codes of practice dealing with various materials. The current guidance includes a hierarchy of recommended options:

- Provision of vertical and horizontal ties as recommended in the British Standards.
- If vertical tying is not practicable, provision of alternative load path in the structure to cope with the notional removal of the untied vertical member in each storey in turn.
- If it is not possible to bridge over the missing member, limit on the risk of collapse to 15% of the area of the storey or $70m^2$, whichever is the less.
- If, on removal of a member, the risk of collapse cannot be limited, design of that member to withstand an applied load of 34 kN/m^2.

For most precast buildings, the last option is rarely necessary. For the purposes of this report, which concerns mainly low-rise buildings, the appropriate level of robustness can be achieved by following the clause 3.1.4 of BS8110: Part 1: 1997 and the corresponding provision of vertical and horizontal ties.

Some experts argue that precast concrete became a scapegoat for the problems that arose from 'social engineering' resulting in ill-matched housing types and social groupings. This took place in many inner urban areas in the 1960's. For example, the specification of heating and ventilating systems that were too expensive for the social groups placed in the high-rise buildings resulted in cold, damp conditions, which of course did not help the public's image of such developments. However, other reasons also tarnished the image of all concrete 'systems'. Ronan Point's construction was a result of over-speedy execution of the Larsen-Nielsen system where insufficient mortar and missed out connectors were to blame. The criticism is that a housing industry in desperate need of dwellings could be vulnerable to such shortcuts. Nonetheless, the public image of precast concrete did suffer significantly, and it has become closely associated with the social malaise of high-rise dwellings.

So, in the public's perception, precast concrete in housing has become unfortunately associated with 1960's social engineering, but it has been proven that actual structural failures were due principally to poor understanding of materials technology, poor workmanship and a lack of quality control on site. However, recent developments mean that precast concrete can show a demonstrable improvement in all aspects of its design and construction associated previously with these problems. It should be emphasised that the problems of the past can be avoided.

Postscript

In 1981, after over forty years in service, structural cracks were discovered during the renovation works on some Airey type houses (Martin, 1999a; Martin, 1999c). This led to further investigations by the Building Research Establishment (BRE) on 17 common precast house types that revealed serviceability problems. In total, about 3,000 houses were inspected visually and 450 houses were inspected in detail; of this number, none were found to be structurally unsafe. The problems discovered as a result of the BRE investigations, were mainly extensive cracking and spalling of the

concrete arising from corrosion of the steel reinforcement within the concrete.
The reports revealed that the corrosion of the reinforcement was due mainly to:

- Carbonation of the concrete
- High levels of chloride present in the concrete
- Low cover to the reinforcement
- Poor quality of the concrete

These problems were created through poor quality of manufacture, poor quality of construction, and lack of concrete materials knowledge. The solutions to the problems ranged from overcladding the existing houses with masonry, to replacing the defective structural elements with traditional building forms. To ensure good quality repair and rehabilitation, the National House building Council (NHBC) was also asked by the government to set up a company to licence appropriate repair systems for repairs to concrete housing systems.

1.4. Current Uses for Precast in UK Housing

A recent survey of house builders and housing associations (see 3.3) indicates that a range of precast concrete products is in common use within UK house building. Some companies have a broad range of experience of precast and some have also studied the potential for panelised or volumetric precast in their designs for houses. The most popular use for precast concrete, however, is in components. This includes walls, beams, floors, columns, panels, lintels, stairs and cills. The benefits of such products for housing are well known. Items such as lintels and cills are mainly stock items, available in standard sizes, often concealed after first/second fix and very economical when procured in quantity. However, in many instances, other elements of the house construction could also employ precast concrete components, such as walls, ground beams, structural frames, foundations and roofs. The potential to widen the market for precast into these areas is significant, and is explored further in Part 4 - The Future. In general, there are three broad categories of use for precast concrete, namely:

- components
- panels (2D construction)
- volumetric (3D construction)

At present, the house building market in the UK is only really taking advantage of just the first of these options, and so the focus of this publication is on the latter two categories.

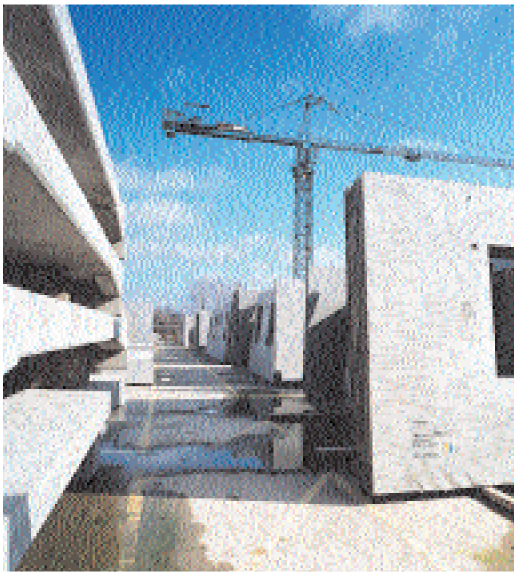
Components: Placing a precast concrete staircase, (courtesy of Tarmac Topfloor Ltd)

1.4.1. Components

As listed above, typical precast components used in housing include walls, beams, floors, staircases and lintels. The technology of such components is well understood and so is covered only minimally by this report. Specification of precast components is determined usually by cost, speed and performance benefits and so components that offer significant advantages will be able to compete against traditional materials. However, greater use is being made of mini-systems of components, or integrated elements. Recent developments in precast components include the rise in popularity of precast foundation 'packages' that reduce trade interfaces and can be used on contaminated or weak soils.

CASE STUDY 1

Roger Bullivant promote their foundation package on the basis that it will be used on contaminated sites and provide fast installation once on site. They design, produce and supply and install every bespoke scheme. RBL produces 3,000 tons of precast concrete every week, including 50 house foundation packages.



Left:Typical wall units in manufacturers stockyard (courtesy of Tarmac Precast Concrete Ltd)

Right: Typical use of beam and block floor system

1.4.2. Panelised Construction (2D)

Generic types of precast single-skin or flat-panel concrete construction are becoming more popular in commercial applications such as hotels and student accommodation. The use of such panels can result in a fast, simple construction process on site followed quickly by finishing trades. This single advantage has been of great interest to hoteliers and other similar clients with high demands on time and quality, but in the somewhat less repetitive housing market, other criteria are relevant. The use of wall panels within housing is currently minimal, but opportunities may arise in the multi-storey apartments market where precast concrete can be used for wall and floor panels. Loadbearing wall elements for instance can be used in either cross-wall or spine wall arrangements; for low-rise housing, the most likely option is cross-wall construction with party walls between dwellings acting as the key structural elements. For single or two storey dwellings, it would be typical to use single storey height wall panels of between 90-300mm thick concrete (depending on whether or not insulation is included) for external walls and 70-100mm thick panels for internal walls.

Loadbearing cross walls combined with precast hollowcore floors can provide up to 12m clear internal spans.

For internal walls and floors, precast concrete offers added value; good sound insulation, structural integrity and a direct finish, if specified. However, its use in an external situation is made slightly more complicated by the need to satisfy thermal insulation and external appearance requirements. Unless used as an insulated sandwich panel (with a 'hardwall' finish on both sides), the precast panel may need to be insulated externally and faced with masonry or another cladding material or dry-lined with insulation and an internal surface finish, e.g. plasterboard. Despite offering speed and performance benefits, the possible need for overcladding can make house builders question the use of panelised construction (Smit, 1999c).

European manufacturers have developed methods of making twin-skinned wall panels that are suitable for direct application of decorative finishes by using fibre-reinforced concrete in place of steel reinforcing bars. Recent versions allow manufacture of fibre-reinforced panels in which each leaf of the wall is only 35mm thick and separated by a 70mm lattice joist (Kahmer, 1999). This system reduces the material volume, weight for transportation and crane capacity on site and allows a greater net floor area. Such production lines are also able to offer some variation in styling of the panels, levels of insulation, electrical trunking, windows, doors and panel connector details, and thus are able to respond better to the needs of their customers. However, in the UK, the thermal and acoustic insulation requirements given in Building Regulations may ultimately determine the level of take-up of some of these solutions (see section 2.6 and Appendix 1).

CASE STUDY 2

Factory Engineered Concrete (FEC) marketed by CV Buchan uses flat-pack structures that are assembled on site. CV Buchan offers design, supply and erection because they wish to ensure quality throughout the whole process. Although FEC is aimed at hotels, prisons and student accommodation rather than housing, there is no reason why it could not be used in housing. For low-rise apartments, Buchan can supply walls, staircases, floors and roof panels. The surface finish is ideal for painting direct and ceilings can take artex direct. Loadbearing and non-loadbearing panels all use ties to prevent disproportionate collapse. The typical speed of erection for 5 storeys is 10 weeks. The panels use a C50 concrete with PFA to reduce blowholes.

CASE STUDY 3

Marshall's 'Panablok' system uses lightweight storey height wall panels to reduce construction time for the inner leaf by up to 75%, and for the overall construction period by 40%. The prefabricated wall panels are a dry fix system with high thermal values and good airtightness; up to 200m^2 can be erected in a day. The reduction in time is said to result in lower overheads. 'Panablok' can be used up to 3 storeys and is BBA certified. It can be delivered from stock in three sizes. The product has been used for the construction of a wide range of developments including low-rise housing, hotels, schools and commercial buildings.

CASE STUDY 4

Bison have a 'cross-wall' solution that offers contractors a way of erecting large-scale developments in short programmes. It was used originally for student accommodation, but is making progress in the hotel and housing markets. The panels are typically 3.4m high and up to 7.5m long, and weigh less than 10 tons. Bison work with their clients using value engineering techniques to enhance speed, trade interfaces and detailing. Advantages for the housing market include speed, minimum wet trades, direct finish, early access and dry working areas. Bison predict that 80% of the market for 'cross-wall' could soon be in apartment buildings rather than hotels. The Bison system has been adopted by contractors Carillion for a £20 million apartment development at Baynards Green in London, and subsequently under a partnership is developing a solution for a further 100 luxury apartments in central Birmingham.

1.4.3 Volumetric construction (3D)

The casting of whole room modules (pods) or individually cast panels joined together in the factory to make rooms is termed volumetric construction and is becoming more prevalent in housing and other markets that use multi-cell structures. Three-dimensional modules are used in hotels, motels, student accommodation and prisons. Volumetric construction uses the benefits of factory conditions to create entire rooms and is used frequently in service-intensive building elements such as 'pod' kitchens and bathrooms in markets where a high degree of repetition and a need for rapid assembly on site make its use highly desirable. The units also offer improved airtightness. In addition to these aspects, a further advantage for the housing market in particular is the ability to create bespoke interiors for the house buyers or occupiers, which is a very important factor in their decision-making. Indeed, modules using other materials have already been used for housing in the UK (see Part 3). Despite these proven benefits and added value, the potential constraints of transportation costs, weight limitations and associations with historical precast concrete 'systems' are still in the minds of the house builders.

Left: Twin-room precast modules (courtesy of Tarmac Precast Concrete Ltd)

Right: Wall panels joined to form student accommodation (courtesy of CV Buchan Ltd)

CASE STUDY 5

Precast Cellular Structures Ltd is a JV of Tarmac Precast Concrete and Composite Structures Ltd. PCSL offers the 'Quadblock' package which includes design, manufacture and erection of precast concrete volumetric units for prisons. The 3D modules can incorporate windows, grilles, doors and M&E services. The precast concrete modules are cast in steel moulds and use prefabricated reinforcement cages. The fully-fitted 4m x 11m double or quadruple room modules can be delivered to site on a low-loader.

1.5. The Market for Precast - Levels of Use in the UK

Precast concrete represents about 25% of the market for cementitious products in the UK and includes a wide range of products used in the construction industry such as blocks, paving, suspended floors, structural frames, other structural elements, bridges, cast stone and architectural cladding (Construction Markets, 1998). However, in the context of this publication, only the use of structural frames, walls and other elements used in the construction of low-rise housing is considered. Of these products, suspended floors are the biggest output in terms of tonnes of product sold per annum, and of all the end uses for precast, private housing is its biggest single use. 45% of all precast concrete goes into housing already: 1.5 million tonnes of precast are used in new homes every year, although most of this tonnage is for concrete blocks.

For all ground floors in housing, at least 60% of the market is taken up by precast. In fact, precast concrete flooring doubled its share of the ground floor market between 1994 and 1999. According to recent industry figures, upper floors could be set for a further increase up to a level of 40% of new homes by 2001. The success of precast concrete in the suspended/first floor market indicates that there is no market resistance to the idea of using it in the housing context. However, given that over 90% of walling in housing still uses traditional masonry construction, then this is a demonstrable market opportunity for precast panels as either 'flat-pack' (2D) or volumetric (3D) precast construction.

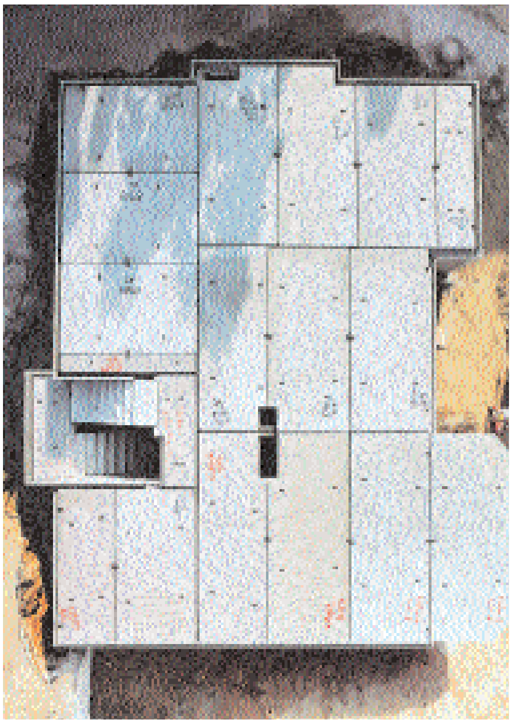
1.6. Other markets' experiences - techniques, systems and products

In contrast to the UK, where the precast industry has everything to gain, in Germany and the Netherlands, the market is much more established and internal competition is fierce. In these countries there are different economic, social and technical factors influencing the specification of materials in housing. As a result of their greater experience with precast concrete, there have been significant advancements in materials and production, which have contributed to the greater use of precast for building elements such as external and internal walls, and even roof panels. Such is the volume of production of these various precast elements, that it has been economically viable to build factories dedicated solely to the production of 2D and 3D precast concrete, as well as simpler components like floor slabs and lintels. Precast concrete is also a popular choice for housing in the USA, Australia and New Zealand. See also section 2.6 and Appendix 1 for a review of EC building regulations.

1.6.1. Germany

The market for precast concrete products in Germany is very healthy. According to the German cement industry body BDZ and the precast manufacturers institute, about 10% of the 250,000 dwellings constructed in 1998 used precast elements for 1-2 storey homes. Furthermore, BDZ claim that the precast market is increasing following the Unification, despite competition from timber frame and thin-skinned plasterboard walling. Indeed, 24% of homes built in 1997 in the former East Germany were prefabricated. Although the value of precast products has increased by 10-15%, profits are hard to come by due in part to added competition from plants based in the former East Germany. A particular feature of the German housing market is the level of homeownership; it has one of the lowest of the EC countries (most people rent their homes).

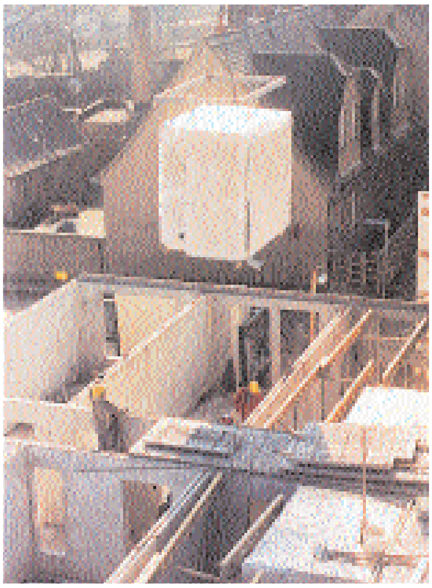
Industry commentators believe the market for prefabricated housing is ripe in Germany. Demands of time, availability of technology, demand for quality, pressure on cost and time plus quality and individuality all favour a greater use of prefabricated components. Through the many precast manufacturers in Germany, it appears that there is scope for a variety of systems in the market. One of the key developments is the use of thin-skinned wall panels as part of an 'open' system of components. Indeed, this product type has been promoted successfully under the name of 'architectural concrete components'. The aim was to reinforce the idea that prefabrication does offer design freedom and flexibility. The Syspro Group markets such product ranges throughout central Europe using a portfolio of brand names to differentiate themselves from competitors (Kahmer, 1999).



First floor overview - Single family housing with precast concrete in Germany (courtesy of Veit Dennert KG)

CASE STUDY 6

Schworer Bautechnik specialises in single family precast homes built to order. The units use lightweight concrete and include windows, doors and electrical recesses that can be placed to a tolerance of +/-1mm. This is a benefit to the owner who avoids paying out again for fitting out costs. The system uses 12m span, hollowcore floors to allow both free use of floor space and a finish suitable for painting direct. The company attributes its success to accurate and speedy batching and storage systems and an investment in new plant.



Installation of bathroom pod (courtesy of PlanTech Badsysteme GmbH)

CASE STUDY 7

Rasselstein Baustoffwerke produces precast concrete bathroom pods that can reduce work-in-connection labour on site from 127 hours to 8 hours, and shorten the construction period of multi-occupancy buildings by up to 6 months. The walls and roof are min. 45mm thick reinforced concrete (lightweight concrete can also be used). Sound reduction levels are between 37-52dB, and the pods offer 60 or 90 minute fire resistance. Each module can be inserted in 15-20 minutes and clients are offered a range of fittings and finishes.

CASE STUDY 8

Veit Dennert claims that its 104m^2 precast concrete homes can be erected and ready for occupation in just five days (Kromer, 1999). In service, the 'Icon House' uses only 58 kWh/m^2/pa, which is lower than current energy efficiency standards in Germany. Four 3m x 8.2m modules are used to create the houses, which can include a prefabricated basement. The cost of the house is said to be 25% lower than the typical costs of a similarly sized home built using conventional methods.

The 'Icon House' demonstrates energy efficiency (courtesy of Veit Dennert KG)

1.6.2. The Netherlands

The tradition of brickwork and masonry construction in the Netherlands is still proving to offer stiff competition for precast concrete in the housing market. Precast now commands 10% of the total housing market and is steadily increasing its market share. This success is due to being able to offer a significant 30% cost saving by using standardised components, flexible manufacturing processes, industrialised building techniques and 'streamlined contracting'. Indeed, the idea of a somewhat flexible system of interchangeable concrete components has proved successful (Belton/Bevlon, 1997). This was confirmed during an expert mission to the Netherlands and Finland by the DTI and the Housing Corporation (Gann, 1999). The visit focused on 'Open Building', a design method developed by Dutch architect John Habraken in the 1960's. Habraken argued that the 'coarse' and 'fine' activities of house building should be differentiated. This separation would result in optimised construction methods and therefore enhanced opportunities for greater flexibility and choice for occupants. Within the Netherlands, the DTI study team found that 'Open Building' included applications in concrete housing designs (e.g. tunnel form). In these structures, cables and conduits were sometimes cast within the concrete or concealed in skirting trunking. The team commented that concrete was used in 45% of all new dwellings and that both occupants and legislators were keen to use new or innovative building techniques.

1.6.3. Scandinavia

In Scandinavia, prefabricated methods for housing construction have a very large share of the market and use considerable amounts of concrete, timber and steel. In Finland, concrete is used in 54% of all new housing; 42% of new homes are constructed using precast concrete (Gann, 1999). Danish company Baderkabiner have been making precast concrete bathroom pods since the 1960's; these have been used on many hotel and university projects in the UK.

CASE STUDY 9

Thermonex in Sweden (also in the UK) produce a panelised concrete basement system and ground floor that is complete on site in 2 days (Pearson, 1999a; Stockerl, 1999). 300mm thick panels are factory-made to order, measure up to 12m x 2.4m and can include electrics and door/window frames. The foundation slab is placed first, then panels are located and propped until the 250mm insulated suspended ground floor is installed. Only the largest basements need 135mm cross-walls for stiffness, and a typical basement can actually be built from just four panels. The combination of a special joint detail and insulating 'X-concrete' (containing lightweight aggregates, expanded clay and expanded polystyrene beads) makes a watertight construction without the need for land drains. Moisture penetrates the panels by only 2-10mm compared to 50mm for normal structural concrete, and the panels also perform well in fire. The cost studies are persuasive; a traditional basement for a detached house can cost £50,000, but using Thermonex it costs about £28,000, and for semi-detached houses just £15,000. Similar systems are available in Germany, under the trade names 'SysproPart and 'Weberhaus'.

1.6.4. Japan

In Japan also, household name companies Toyota and Mitsubishi are known for house building as well as the manufacture of cars. In this market too, the notion of factory-made housing is popular and successful. One large house building contractor, Sekisui, builds over 100,000 flat-pack or modular homes per annum; it has been producing homes like this since the 1950's and has produced 1.25 million homes since that time. The market strength of prefabricated housing in Japan attracted a UK expert delegation in 1996, which found that prefabrication was indeed very popular, but that the housing market there was really quite different to that of the UK (Bottom et al., 1996). The expert mission to Japan found that the housing market was characterised by:

- Considering housing as a product in its own right
- The dominance of new build (no second hand housing market)
- An established government & industry framework for innovation
- Industrialisation as a means to choice, quality and flexibility as well as economy
- Use of electronic modelling to improve process
- A willingness to exchange ideas

The Japanese market builds eight times more houses than the UK per annum, although the population is only double. Timber and steel systems are used as well as concrete panels, in-situ frames and concrete filled steel composites. Precast concrete dominates the apartments market. House builders are much larger than those in the UK, and survive on the profits from construction, not from the value of their land banks. This is so much the case that the relationship between the house builder and the buyer is much closer, and much more 'customer-focused'.

Sekisui sells through more than 2,700 licensed land and house dealers to a well-informed customer base. Most housing companies invest substantially in R&D to define the minimum number of individual components required to provide the widest range of options for the customer (i.e. 'agile' production). 3D modelling of design options is thought to be a major draw for potential customers. Indeed, the use of IT is also likely to impact throughout the delivery cycle (Atkin, 1999). Japanese companies such as Shimizu are actively investigating computer-integrated design, manufacture and construction in a bid to save costs and labour.

Housing is designed and made to the buyer's requirements and tends to make maximum use of land available for development. Housing itself is thought of as a consumer product, and has a design life of 20-40 years only. Thus, prefabricated industrialised housing is perceived as a bespoke, high quality product and customers are also shown evidence of the manufacturing processes involved.

1.6.5 USA

In the USA, 30% of all housing is prefabricated. Although much low-rise housing is timber-framed, concrete systems are being used increasingly, particularly in areas that are vulnerable to environmental hazards such as hurricanes and tornados. Information from the PCA (Portland Cement Association) suggests that panelised 2D precast concrete systems are used for low-rise housing in several states (VanderWerf & Munsell, 1995). Although the potential benefits of quality, less labour costs and reduced site time are accredited to precast concrete, buyers had been discouraged by the previously plain appearance of panels, risk of water penetration and difficulties of installing insulation. However, recent development such as improved moulds, improved concrete mixing techniques, availability of rigid foams and a range of surface finishes have effectively reversed this trend. In a series of interviews with US house builders, the PCA found that up to 70% chose house building 'systems' on the basis of cost/value alone. Finishes, flexibility and thermal mass were perceived as incidental benefits. However, it is clear that the traditional list of perceived benefits of concrete construction has been extended to include these factors and others such as speed and ease of construction; the idea of prefabrication is gaining value in the US house building market.

CASE STUDY 10

Two companies producing 2D precast concrete panels are profiled in the PCA's publication. Both use plain precast panels stiffened with internal ribs that form the support points for dry lining. The first (Royal) uses 140mm thick precast concrete panels with steel surrounds to obtain 'bolt-together' connection details, steel studs for internal finishing and rigid foam insulation. The panels are designed for single storey dwellings and can incorporate brick ties if a brick skin is specified. An alternative wall system supplied by Superior is available in a range of heights from 1200mm to 3000mm (approx.). This option uses concrete ribs with pressure-treated timber 'nailers'. Both companies offer warranties and costs are about £40-60/m^2 including finishing.

1.7. Summary

The history of precast concrete in housing has featured a broad range of systems, some of which have proved more successful then others. The highly-publicised Ronan Point incident and 'social engineering' of the 1960's has resulted in an unfortunate, but in many instances, unnecessary stigma being attached to precast concrete. The current portfolio of products available both in the UK and elsewhere are demonstrating that there is a growing market interest in the generic benefits of prefabrication and in the specific benefits of precast concrete. Considering the success with which precast concrete has penetrated the suspended flooring market, there is certainly scope for a wider use of precast components, panels and volumetric construction in housing.

Part 2 - Design and Construction with Precast Concrete

2.1. Introduction

This part of the report presents an assessment of both the broad benefits of using concrete and the specific benefits offered by precast concrete (2.2 and 2.3). Key design and construction issues are also evaluated in section 2.4 and 2.5. A review of EC Building Regulations is referred to in section 2.6, the full version of which can be found in Appendix 1. The scope of this part of the report is not limited strictly to house building; some aspects are equally applicable to other similar uses for precast concrete.

Precast concrete contributes to on-site efficiency (courtesy of Veit Dennert KG)

2.2. Generic benefits of concrete construction

With reference to structural and non-structural use of concrete in buildings, there are a number of key benefits that are inherent to concrete as a material, wherever it is used. Clearly, such benefits can complement those offered specifically by precast concrete which are described in section 2.3. The advantages considered relevant to house building are fire resistance, thermal performance and sound insulation.

2.2.1. Fire resistance

The performance of concrete in fire is well documented. The requirements for protection and surface spread of flame in low-rise housing are well within concrete's capabilities in this aspect. For example, a 150mm thick concrete wall can provide over 90 minutes fire resistance, which is in excess of what is required for most housing. Exposed concrete has a Class 0 surface spread of flame rating and the relatively modest nature of the structural elements in housing mean that complying with stability requirements is straightforward. Thus, concrete has an established and inherent advantage over both metal and timber solutions in terms of fire performance.

2.2.2. Thermal performance

Normal density concrete is able to contribute usefully to the thermal comfort conditions within a building (other solid construction materials can perform a similar function). Concrete's thermal capacity allows heat to be absorbed and stored in the building structure and either re-radiated or 'purged' during cooler periods. This has the potential to remove the need for air conditioning in many buildings, when used with effective solar control and ventilation (Glass et al., 1999). In housing, there is currently a growing interest in providing 'comfort cooling' as a selling point. The impact of such systems is well known, and so the opportunity to use concrete as a more sustainable alternative to HVAC systems should be a tangible benefit to house builders. Fabric thermal storage can provide considerable payback benefits over time to the occupier. In New Zealand, recent tests to compare the energy efficiency of concrete and timber homes found that a concrete house contributes a cooling effect of 3-4°C during the summer months (Thomas, 1999a; Thomas, 1999b).

Moreover, concrete can provide a level of internal temperature stability that is simply not attainable with lightweight construction. The proposed revisions to the Building Regulations Part L could be advantageous for concrete (Cook, 1999). The revisions include the increase in insulation requirements and mandatory airtightness testing for both new and existing buildings. The new U value of $0.3W/m^{2}{}^{\circ}C$ compared with the previous 0.45 could mean a doubling of insulation thickness but concrete's thermal mass will also help keep the building cool. Indeed, several UK research projects have shown that buildings with exposed concrete internal surfaces can contribute significant degrees of cooling (>5°C in some instances) (Glass et al., 1999). Airtightness tests would favour precast because of the lower number of joints and potential leakage points (unlike frames or masonry).

However, in some high thermal mass buildings, during winter months there may be a slight penalty to pay in terms of space heating demands; to date this has been analysed only for office buildings (Barnard, 1999). The decision to utilise the thermal capacity of concrete can affect a building's design, because the maximum effect is achieved where the internal surfaces of concrete are exposed. To achieve satisfactory thermal insulation (wall) values, consideration also needs to be given to the location of the insulation materials which can be placed on the external face of the wall, the internal face of the wall, or internally to the wall, as a sandwich construction. In all cases, it is good practice in wall construction to consider carefully the position of the insulation relative to the dew point, which should prevent unwanted interstitial condensation occurring. For floors, there are several design alternatives to maximise the use of concrete's thermal capacity. Exposed ceilings (soffits) offer a 'passive' non-mechanical solution whereas 'active' systems such as Termodeck provide a greater degree of control through use of air-driven ventilation in the slab.

2.2.3. Sound insulation

Unlike steel or timber systems, concrete offers the possibility of housing that is intrinsically solid, with high acoustic performance. For all solid walls, the mass law for sound reduction applies, where a doubling of mass improves the Sound Reduction index by 4dB. Concrete can provide good sound reduction values provided joints and openings are detailed properly. For example, a 150mm thick concrete wall can provide over 50dB reduction in sound transmission between rooms, dwellings and from external noise sources such as traffic. Of course, precast concrete houses also benefit from having less joints or voids than traditional masonry construction, which will also improve the sound reduction qualities of the dwelling.

2.2.4. Durability and robustness

Concrete can provide a dwelling with a solid and durable construction that will prove resistant to impact damage and be easy to maintain provided all the normal standards and regulations are adhered to. BS8110, Eurocode 2 and other standards specific to precast concrete ensure that concrete is used safely and appropriately within buildings to provide a robust, durable and stable structure. The resulting dwellings will be long lasting and simple to maintain.

2.3. Specific benefits of precast concrete

The idea of prefabrication of building elements in factory conditions brings with it certain inherent advantages over purely site-based construction (Taylor, 1999). Whatever the product being manufactured, working in a factory offers weather-independence, 24 hour working capabilities and economies of scale and scope. In terms of precast concrete, and with reference to the Oxford Brookes University market survey of house builders (described in section 3), it is clear that people perceive that precasting offers some very particular benefits in addition to those offered generally by concrete. Speed, quality and efficiency were all cited as specific attributes of precast, and of all those speed was the most highly regarded. Although people's experiences of precast concrete vary considerably, those who took part in the Oxford Brookes University survey cited speed, economy and quality as key advantages.

2.3.1. Speed

In parallel with initiatives arising from the 'Rethinking Construction' Report (see section 3.4.1), there is much market interest in the advantages of treating construction as 'on-site assembly' of components manufactured in a factory environment. This approach can offer faster, cleaner and safer working conditions on site and so be of benefit to clients, contractors and others involved in the process. Precast concrete elements can be used in this way provided the manufacturer has adequate notice of requirements

Speed of erection on site (courtesy of Belton/Bevlon) and is able to pre-plan the design of the components in line with the sequencing of on-site activity. Some people perceive that factory made components require a long lead-time (period of notice), but designers are advised to contact prospective manufacturers as soon as possible to take advantage of their expertise in this aspect.

Fast construction on site means the project reaches hand-over more quickly, and so the client can occupy or let the building earlier. Consequently, there are savings in land, labour, rents, overheads and financing costs, and a faster return on investment. Furthermore, if less time is needed on site, then there is less pressure on the design team to find a suitably lengthy 'weather window' for construction activities. According to respondents in the Oxford Brookes University survey, there is also an advantage in being able to construct with prefabricated components because this requires a less skilled labour force than traditional construction methods. Hence, this de-skilled and 'dry' assembly process expedites the programme even more as there are less 'wet' trades (and less trade interfaces) to consider, so fitting out activities can start earlier. Of course, this may well be accompanied by a shift of tradespeople from site-based working to factory-based working, creating a multi-skilled work force in the factory environment (Barry & Cronin, 1999). The increased use of inter-operability, IT and bar-coding technology is also likely to speed on-site activities associated with assembly of precast component parts.

2.3.2. Quality

One of the key perceptions attributed to production in controlled environments such as precast concrete factories is that the greater degree of control (and the lesser degree of risk) will result in a higher quality product compared to its on-site equivalent. The ability to work in a weather-independent and controllable environment means that strength, surface quality and consistency, and detailed design features in precast concrete components should be much easier to achieve. Indeed both the material and dimensional properties of the product should benefit from such a production environment.

High quality clean factory environment (courtesy of Veit Dennert KG)

Most designers recognise that prefabrication and factory production also result in much finer levels of tolerance in the product itself; this is a key advantage for speedy and accurate on-site assembly operations. Where appropriate, precast concrete can be designed to have a degree of flexibility. Once on site, Professor Stephen Gage of University College London considers that precast components offer better 'line and level' than traditional masonry walls for example, which is of benefit to subsequent fit-out activities. The quality of surface finish attainable in a factory can be higher than that achievable on site because specialist mould-makers are often employed and because battery casting of repetitive components allows the manufacturer to invest in high quality, high re-use formwork materials.

Although precast concrete can be used for very high quality architectural surface finishes this should be considered in the light of the destination of the product. In housing, it may be appropriate to cast a high quality surface for internal applications that can be painted or papered direct, but consideration can also be given to a more decorative finish for external panels. Although the Oxford Brookes University market survey indicates that brick/masonry finishes are not crucial to the house builder, there is certainly evidence from another survey ('Kerb Appeal') that house buyers are keen on traditional finishes (see 3.3). So, there may be a need to cast cut bricks into facing precast wall panels to satisfy consumer demands in this respect; this would produce a high quality single leaf wall, thus saving valuable floor area over a cavity wall solution. Indeed, the addition of 'easy finish' wall panels would extend the precast portfolio to a 'one-hit' site operation providing foundation, floor system, walls, suspended floors, partitions, external walls and possible even roofs. Finally, value could be added to the product range by offering pre-installation of doors and windows, and a choice of finishes etc.

2.4. Key issues in concrete construction

As described in section 1.3 of this report, there is a stigma surrounding the use of concrete for housing, and this has influenced take-up of the material in that market to date. The concerns raised as a result of the use of concrete systems outlined the need for designers to consider carefully the use of concrete in the context of housing. With all reinforced concrete there is a need to provide sufficient cover to reinforcement; achieving the level of cover recommended will prolong the life of the structure by preventing corrosion of steel reinforcement and thus spalling of the material. Adequate cover to reinforcement is also important in ensuring concrete elements satisfy fire resistance requirements (where applicable). Prevention of excessive moisture ingress into concrete and adequate ventilation of elements will assist in reducing the adverse effects of condensation, chemical attack and mould growth. The connections between structural concrete elements are key to providing stability, and so these should be detailed with care by a structural engineer. BS8110 and Eurocode 2 provide further details on the design of structural concrete. Various general safety standards and codes of practice govern construction of concrete buildings on site; these are designed to protect workers from accidents and other hazards associated with cement and concrete handling and assembly.

In summary, concrete construction can provide both short and long term benefits provided that designers and constructors adhere to the relevant standards and codes of practice.

2.5. Key issues in precast concrete

Although designers are aware of the typical benefits of precast concrete, they sometimes cite inflexibility, appearance and service delivery issues as key barriers that might prevent further use. However, in the Oxford Brookes University survey (see section 3.3), 60% of interviewees stated that they could not think of any specific disadvantages of using precast concrete.

2.5.1. Perceptions of cost and value

Perhaps the most difficult to assess of all the aspects of factory produced concrete is the issue of cost. On one side there are the potential savings offered by mass production and simple assembly, but alternately, the cost of transport, erection and attendant overheads of operating a production facility must also be borne. Furthermore, the fact that detailed costs for precast concrete are not readily available in published sources such as Spon and Laxton etc. means that there is a natural wariness on the part of the customer.

Off-site production of staircase components (courtesy of Tarmac Topfloor Ltd)

If new products are to be offered to the housing market, then the capital investment required on the part of the manufacturers may prove prohibitive. So, in terms of supply and demand, this may be a 'Catch 22' situation. However, if existing facilities can be adapted, and provided manufacturers can partner house builders, then there is scope for carrying out small scale projects for which the cost penalty is minor, negotiated and agreed.

A further point of interest is the balance of labour required for different types of precast concrete. Whereas components require less labour in the factory and more on site, 2D and 3D precast concrete requires more labour in the factory but less on site. The costs associated with labour are complex, but it is clear that workers based in a factory could enjoy arguably better conditions than their equivalents on site (see also section 2.5.5).

Research in New Zealand suggests concrete housing may incur only 2% additional construction costs over timber frame construction. Clearly this difference is minor and could be recouped by the occupier in life-cycle benefits such as energy savings within a short time. Indeed for housing associations the publication of whole-life or even part-life costs would be useful; their interest lies in the long-term value offered by precast housing. With precast concrete, there are potential savings to be gained on site from reductions in time-based factors such as:

- Finance costs (money needs to be borrowed for less time)
- Time-related preliminaries (e.g. staff, plant, access, accommodation, power and cleaning)
- Additional overheads (e.g. rent for storage of equipment)

NB: A comprehensive method for appraisal of savings associated with time can be found in 'The Cost of Time' by the University of Reading's Production Engineering Group (Gray & Green, 1999).

2.5.2. The image of precast

The 'Kerb Appeal' research showed that housing occupiers are not concerned with the structural form of the house, as long as it appears solid and durable (see section 3.3). In this respect, they have no particular preference for masonry or concrete. However, concerns do arise when consideration is given to using non-traditional facing materials, in say the external elevations; there is a strong preference for traditional masonry appearance. Contrary to this however, there is widespread acceptance of the use of some visible non-traditional (precast) elements such as reconstituted stonework. This is seen as a high quality product adding value to a property. Thus preconceived notions of how non-traditional materials such as precast concrete can be used in housing need to be challenged. House builders claim that the public has a low opinion of precast concrete, but there is evidence of a distinct lack of awareness and knowledge of precast amongst house builders and the public alike. Raising the profile of precast concrete may be difficult. As explained in Part One, the historical association of the material with system building means that precast concrete may need to re-invent itself to be able to compete in the housing market. In this respect, the visual or architectural appearance of concrete may be indicative of a wider issue in housing. Planners are increasingly demanding in respect of houses, so the perception from house builders and developers that only certain styles will achieve success in the marketplace is well founded. However, although standard house types have often commanded good prices in the past, cultural socio-economic and demographic changes in the UK mean that different house designs and types may be desirable.

2.5.3. Structure

With 2D precast concrete panels, continuity and transfer of loads takes place between elements through ties (requirements for these are in BS8110). For 3D systems, continuity can be obtained at the corners of each module. Joint design for precast concrete is no different from in-situ reinforced concrete in that the forces within joint zones can be analysed in terms of internal struts and ties. The key difference is the need to deal with tolerances whether these are design tolerances or unintentional dimensional variations. Manufacturers of precast concrete maintain that their products can be designed and produced to very fine tolerances, but note that it may be difficult to co-ordinate such accurately made components with other construction activities when assembly is taking place on-site.

There is a view that the use of structural precast concrete results in members that, because of their lack of continuity, are effectively oversized for their purpose. This is in contrast to an in-situ concrete solution for example which may be slimmer, or less expressed, in section due to the continuity between elements. Nevertheless, for housing this is not likely to be an issue simply because the elements are of a relatively modest size. A further point is joint design. It is possible that the need to provide some form of continuity and connection between precast elements necessitates rather more careful consideration of joint design than is the case for some other construction methods. Joints must have sufficient strength and be able to avoid sudden failure modes and deal with manufacturing and construction tolerances (this is true of joints in any form of 'assembly' type construction). However, the need for slightly more effort in joint design is not considered to be a major reason to deter people from using precast concrete.

2.5.4. Flexibility and services

The Oxford Brookes University survey of house builders revealed that there was some disagreement as to whether precast concrete was a flexible enough construction method for housing. Respondents criticised larger precast components (panels and volumetric) for being too regimented and said that they would have to be convinced of such products' cost and quality effectiveness in practice.

A key factor in the debate about the level of flexibility offered by precast concrete appears to be the issue of services provision. The issue centres on to what extent servicing should be integrated or incorporated into the concrete itself. Clearly there is the example of systems like Termodeck in which the structure and heating system are part of the same product, but some people argue that future flexibility of housing stock relies on servicing being more readily adaptable. However, if services are not concealed within the concrete, then these need to be accommodated in trenches, raised access floors, skirting, ducting or trunking.

Integrating and pre-planning of structure and services (courtesy of Veit Dennert KG)

Taking more highly serviced building types as a precedent, the main service to be concealed is usually electrics and lighting, rather than HVAC etc. Nevertheless, the UK predilection for hot water heating systems using radiators, rather than underfloor systems, may also influence the take-up of precast in housing. In essence, precast for housing might have to offer well co-ordinated structure and servicing rather than some sort of high-tech, wired-up wall or floor. For house buyers, the ability to nail, drill and fix to walls and floors may be of far greater importance than any other aspect of flexibility.

There are several options to address this problem, including; developing innovative fixing or adhesive systems, such as those designed for thin leaf dry-lined cavity walls using lightweight or foam concrete panels, or casting a thin layer of softer material on the inside face of wall panels. For tenanted housing where significant changes to the building fabric are likely, it may also be necessary to incorporate knock-out wall panels. With precast concrete it is feasible to provide both knock-out panels and movable panels as required.

2.5.5. Service delivery (procurement)

From section 1.6, it is clear that the level of service associated with precast components varies between countries, with Japan being an exemplar in this respect. Professor David Gann of Sussex University believes that UK house buyers should be offered the same level of service and choice as buying a car for example (Bottom et al., 1996). This level of choice would elevate precast from a commodity to a value-added product in the eyes of the consumer. Indeed, the service delivery approach offered by manufacturers could be extended to reflect the changing nature of the UK housing market. The client group for precast includes a wide range of bodies (house builders, self-builders and housing associations), so the EC approach of marketing a portfolio of complementary products might also be appropriate in the UK. Most house builders tend to sub-contract most site activity, so the opportunity to bring about change is significant. Precast could be used in a sub-contract, rather than a supply-only activity. For example, most precast flooring is already sold on a supply-and-fix basis. The idea of manufacturers offering the supply, fix and completion service is unlikely: they would need to partner a house builder to get this to work in practice.

In all, there are three options for precast housing:
- Design, manufacture & supply of plain components, panels, pods etc
- Design, manufacture and supply of complete integrated solutions including services and finishes
- Both of the above to the point of completion on site of a dry envelope

A further paradigm in which partnering may be a genuine alternative relates to investment. Factory-based production can require significant initial capital investment, which is anathema to construction companies such as house builders that have relied traditionally on land banks for their assets.

So, unless the companies can partner with another with fixed assets (e.g. an existing precast factory), then the potential benefit of reduced operating costs will simply not be enough to make them invest in new production facilities. Ove Arup & Partners argue that the added costs of factory production must be balanced by a reduction of costs on-site. The only way they believe this can be done is to reduce site-based labour to a minimum (materials costs are at a minimum, and can only be reduced marginally by cutting wastage).

The efficiency of factory based production methods (courtesy of Tarmac Topfloor Ltd)

2.6. Review of European Building Regulations

In order to explain briefly the legislative context of using precast concrete in housing and to establish key differences between the UK and other EC countries in this respect, a review of the EC building regulations was undertaken separately by Brian Keyworth of Brian Keyworth Architects. Appendix 1 contains a summary of the Institute of Building Control (IBCO) review of building controls, regulatory systems and technical provisions in the major member states of the European Community and EFTA countries. The summary includes information from Germany and the Netherlands and covers:

- Mechanical resistance and structural stability
- Safety in case of fire
- Protection against noise
- Energy economy and heat retention

As noted in the Appendix, it would appear from this study that building regulations in other European countries are generally similar to UK requirements although there are inevitably differences in the way requirements are expressed and the criteria by which they are measured. It would be necessary to carry out a very detailed design and costing assessment to establish the effect of the differences in requirement but it seems unlikely that these would radically influence the method of construction selected.

A detailed investigation of Dutch and German regulations does not bring to light any specific requirement (or lack of requirement) which would be likely to make the use of precast concrete construction more advantageous or economically viable than would be the case in the UK. However, thin-skin twin wall construction (i.e. two 35mm leaves of fibre-reinforced concrete separated by 70mm lattice joists) is a popular application for precast concrete in Germany. To attain approval for this type of system with reference to sound insulation standards, the following guidance is given based on current UK Building Regulations:

The Regulations for sound insulation in England and Wales are in functional form. These are supported by technical guidance in Approved Document E. This guidance covers common constructions, but also makes provision for innovative systems by offering a performance test which allows for approval of constructions which are similar to the one tested. Part E is currently under review.

The full report of the IBCO Review by Brian Keyworth is available on request from BPCF.

2.7. Summary

The performance benefits of concrete construction are well known. The material has inherent advantages in terms of fire resistance, thermal mass, acoustic insulation and durability, and these can be optimised by working to acceptable 'best practice' guidelines. Precast concrete shares these benefits, and in its own right can also offer fast on-site assembly of a range of high quality products. For housing in particular, the future needs of the occupants demand consideration of other issues such as services integration and adaptability of internal spaces. In combination with the requirements of regulations etc, these factors may need to be addressed further to promote the use of precast in low-rise housing projects.

Part 3 - Current Drivers in the Housing Market

3.1. Introduction

External factors that may also influence the take-up of precast concrete are described in this part of the report. Trends within the UK housing market in general are covered in section 3.2, and various market surveys are examined in section 3.3; this section incorporates findings from a survey by Oxford Brookes University, undertaken specifically for this report. Other market 'drivers' are noted in section 3.4. This is followed by an overview of the use of other materials used for prefabrication in the UK.

3.2. The UK housing market

This section illustrates how recent national and local changes within the UK housing market could affect the take-up of both precast concrete and other industrialised construction methods.

Higher density housing in traditional style on brownfield site (courtesy of BCA)

3.2.1 National trends

Key statistics

- In 1999, about 200,000 houses were built in the UK
- Almost half of the UK's housing stock is over 50 years old, 23% of it is over 80 years old
- The average dwelling density is now less than three persons per dwelling
- The number of people aged 65 and over will increase to almost 20% by 2020
- 90% of new housing is built using traditional brick or masonry construction
- Although owner occupation is the dominant form of tenure currently, its growth is slowing
- 80% of new homes are built speculatively (this figure is falling)
- 20% of new dwellings are built by housing associations and housing trusts (this figure is rising)
- Housing associations expect to start schemes for 30,000 homes per annum (just 60 associations account for half of this number) which are worth £2bn
- UK government is insisting that 60% of all new housing should be built on brownfield land
- There will soon be a shortage of dwellings suitable for the huge rise in one person households
- Almost one third of housing association dwellings built are 1 or 2 bedroom flats

Predicted major changes in demography (population trends) in the UK could have a significant effect on the nature of the new build and rehabilitation markets for housing. The projected increase in demand for single or small family dwellings may presage a rise in 'starter' size homes. However, coupled with the predicted reduction in availability of suitable sites, then low to medium rise apartment buildings may also be in demand. A reduction in the average size of UK homes is likely to mean that house builders and housing associations will look upon industrialised and volumetric forms of construction more favourably. The need to provide small size units on confined urban and brownfield sites will encourage the use of modular, prefabricated housing which can be assembled rapidly and easily on site.

Urban intensification (including the utilisation of brownfield sites) is an issue somewhat beyond the scope of this report, but it may well influence the patterns of house building in the future. Currently, more than 50% of new dwellings are built at densities of less than 20 per hectare. However, a recent revision to Planning Policy Guidance Note 3 states that 'although a minimum density of 20-25 dwellings per hectare can be set, densities should be increased where public transport provision is good'; this favours developments of greater densities such as apartment buildings in urban areas. In parallel, planners in the South East have also noted the idea that new housing stock should not be approved unless accompanied by improvements in infrastructure. The recently formed Urban Task Force intends to highlight the attractions of urban lifestyles and relieve pressure on greenfield sites and road transport by developing new and appropriate mixed tenure developments (Feilden, 1999; Long, 1999d; Ridout, 1998). However, the House Builders Federation claims that the current planning system is restrictive in both procedure and its effective controlling of land prices. The HBF suggests that the cautious lenders are also highly influential; '(the HBF wants) to encourage innovation in housing but there could be problems convincing first, the customer, and second, the financial institutions'.

Table 1: Housing Output Forecasts (%)

	2000	2001
CFR	3.5	3.1
Hewes	6.0	4.7
BMP	4.5	1.5
Average	4.7	3.1

Table 2: Housing Starts Forecasts (%)

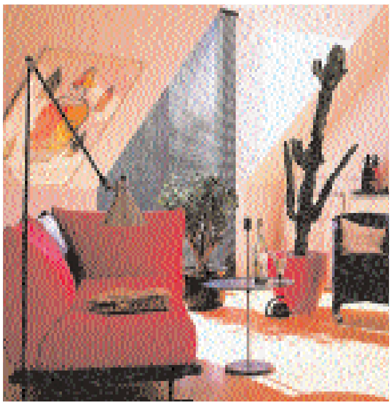
	2000	2001
CFR	1.1	-1.6
Hewes	5.6	-0.5
BMP	3.8	-1.6
Average	3.5	-1.2

Tables 1 and 2 indicate that housing starts are predicted to peak in 2000, followed by a continuation of completions throughout 2001. In general, these figures reflect the UK government's prediction of a 3.8 million increase in households (from 1996 to 2021), but in reality this huge housing development programme is more likely to have a staggered start over the next few years. However, there is no certainty that this number of homes will be completed, and it is possible that the number will be reduced and accompanied by a campaign for increased refurbishment and rehabilitation of existing housing stock. Thus, the housing market over the next few years will be determined by government initiatives, changes in housing density and quangos such as the Urban Task Force. This could mean that take-up of precast concrete is set to be influenced by a very broad range of housing stakeholders.

3.2.2. Design life and flexibility

The issue of design life for new and existing homes is complex; guidance and attitudes vary in different sectors of the housing market. There appear to be two key areas to address:

- Residents and their lifestyles
- Design life of the building itself (and its component parts)



Typical interior view from the precast concrete 'Icon House' (courtesy of Veit Dennert KG)

The problem of flexibility in use has been addressed to some extent by the Joseph Rowntree Foundation's report 'Lifetime Homes' which sets out design guidance and is being incorporated into planning legislation throughout the UK (Bright, 1996). For the Joseph Rowntree Foundation, rebuildability and rehabilitation are seen as important indicators of sustainability. The rise in the elderly population means that people staying in one dwelling for their lifetimes becomes more likely and so the issue of future flexibility is vital in new housing design. The report includes design guidance for both elderly and disabled residents.

The Scheme Development Standards published by the Housing Corporation guide housing associations in their designs (Housing Corporation, 1998). The Standard includes access and mobility, minimum space requirements, sanitary provision, sound and thermal insulation and number of socket outlets. Changes in design life standards for homes are reflected in the Scheme Development Standards as recommended 'tests of performance' for housing sustainability. Under this section, the Standards recommend that scope for future adaptation can be improved by facilitating internal re-modelling and extension within the roof space.

Clearly, the nature of housing associations as registered social landlords (RSL) effectively means that these organisations have a vested interest in constructing dwellings with inherent longevity, flexibility for the future and ease of maintenance. These factors are difficult to balance, and despite there now being a greater expertise in life-cycle costing of materials etc, it is very difficult for the associations to predict future demographic trends with any accuracy. So, the specification of new build homes to account for life-cycle changes (rehabilitation) is not a straightforward process; even speculative house builders are under pressure to extend design life. It is feasible that housing associations will demand more price and time certainty from their suppliers, which will allow them greater flexibility in other design issues. The key difference between housing associations and house builders in this instance is that the associations will consciously invest quite heavily in the design effort in order to minimise rehabilitation and maintenance costs in the future.

So, the housing associations are 'knowing' customers that are likely to innovate to achieve goals. It is feasible that they would demand testing of thermal and acoustic performance as well as testing of lender approvability for precast products. They may even request a product guarantee for design life. This is a controversial issue; associations may be responsible for 120 years worth of rehabilitation and maintenance, but there is little point in designing for such a life span if significant internal rearrangements are likely in that time. Non-housing association dwellings might be deemed to satisfy with just 25 year life spans, but for PFI agreements, it should be noted that the minimum design life is 60 years. Current estimates of 'design life expectancy' for buildings suggest that in a normal 50-60 year life span, elements might be refurbished or replaced at about the following intervals (after Duffy, Brand and Habraken (Gann et al., 1999)):

- Finishes 5 years
- Internal fittings 10 years
- Services 20 years
- Structure 50-60 years

Thus, everything apart from the main structure should be designed to anticipate refurbishment, modification, replacement and/or improvements during a home's typical design life.

A DTI/Housing Corporation study visit to the Netherlands and Finland (see also 1.6.2.), analysed the notion of flexibility and choice in relation to prefabricated construction methods for housing (Gann et al., 1999). In particular, the study focused on the relationship of residents' choice versus life-cycle flexibility. The study concluded that UK house builders had a limited understanding of how value and customer choice could be improved, indeed house builders interviewed felt constrained by economic, procurement and cultural factors. Professor Gann et al. concluded that UK house builders and RSL's were not likely to adopt the flexible 'Open Building' techniques used in the Netherlands which offer long term internal flexibility for residents and landlords until there were changes in attitudes towards tenure and whole life costing (i.e. sustainable design). To achieve both flexibility and choice, the study team recommended that house builders and RSL's should:

1. Survey the likes and dislikes of occupants
2. Confirm what factors add cost and what factors add value
3. Establish more clearly exactly what parts of a dwelling need to change and at what time

3.3. Market Surveys

In addition to impacts likely to arise from changes in planning legislation, demographic shifts and design requirements, people's perceptions of housing can also play a significant role in defining the market directions and design preferences offered by house builders. This section outlines key findings from recent surveys carried out in the UK housing market.

3.3.1. House buyers and the public

Comprehensive surveys of the public's attitude towards housing are unusual; more often such surveys are carried out with a particular question in mind, due simply to the scale of effort required to complete the task. The 1998 market survey 'Kerb Appeal' involved about 1,000 participants and reported on public views towards new build houses (it excludes apartments and all existing homes) (Popular Housing Forum, 1998). The findings claim that the potential buyers felt that new houses were generally 'cramped, boxy and lacking in individuality', but there was a divergence of opinion about the relative importance of visual appearance. Other factors were thought to be more persuasive to the potential buyer than aesthetics alone; size, shape and traditional design features were thought much more influential on the decision to buy. Although people enjoyed architectural references to traditional building styles, they did not like this as an 'add-on extra'.

One of the key findings of 'Kerb Appeal' was that idea that new houses in the same area should be 'different but the same' which demands that the house builder achieves a balance between conformity and individuality in design. Of all the possible design criteria, the most popular with the public were 'shape/proportion', 'roof' and 'windows'. Potential house buyers rated ease of maintenance and suitability for their family highly. They also thought the image of the whole neighbourhood was more important than individual houses. Density proved to be a more difficult issue; people wanted space around houses and their own gardens, but not at the expense of greenfield sites. An ideal development was said to be safe and quiet. In general, the conclusions from the 'Kerb Appeal' survey have proved to be influential and could have far-reaching effects on the way housing is designed.

The preferred solution: Traditional construction and high performance hollowcore (courtesy of Bison Concrete Products Ltd)

A recent survey by MORI for the Traditional Housing Bureau suggested that 94% of people prefer traditional construction to new lightweight steel or timber framed versions (Fairs, 1999a). People believed that a heavyweight construction would hold its value better, last longer, was more suitable for shelving and was better thermally and acoustically than the lightweight options. The 'traditional' package overwhelmingly approved by the respondents included concrete floors. On a broader level, the recent conversion and rehabilitation of several London tower blocks indicates that house buyers attitudes towards housing are perhaps more flexible than surveys like 'Kerb Appeal' suggest. Both high-rise Keeling House in East London (by Sir Denys Lasdun) and Erno Goldfinger's Trelick Tower offer spacious flats and good views (Smit, 1999d). If current market prices are a good indicator, then the potential for new build and rehabilitated prefabricated housing is considerable. However, this trend is contradicted by a survey by MORI for the Alliance & Leicester building society which found that the majority of people questioned wanted a new (spec-built) house or bungalow; only a few preferred the idea of a secondhand property or high-rise apartment.

According to Professor David Gann, cultural factors should not be ignored in matters of technology transfer (Fairs, 1998; Gann et al., 1999). Although Gann suggests that above all house building should be thought of as a total process and to 'use innovative technology to reduce costs, eliminate defects, minimise waste and save time', the needs of the consumer must also be addressed. Indeed, according to a survey by '2000 Homes', 83% of people wanted some input into their house layout and 79% wanted flexibility at a later stage (see also 3.2.2.).

3.3.2 House builders and housing associations

As part of the investigations of the Precast Housing Feasibility Study Group, a market research exercise was undertaken by Oxford Brookes University to ascertain the attitudes of a sample of the Top 50 UK house builders and Top 50 housing associations towards the use of precast concrete in housing. Just over 20% of the companies were interviewed, but as the Top 50 house builders construct 1/3 of all homes built in the UK, those interviewed represent at least 15% of the market (Birkbeck, 1999; Bazlinton, 1999). The survey focused on house builder's views of their own needs, their customers' needs, and of the perceived advantages and disadvantages of using precast concrete for housing. Findings that relate specifically to precast concrete are referred to in Part 2.

When asked about their own company's needs, respondents stated clearly that commercial value was of the highest priority, However, it is worth noting that architectural appeal was also important to the house builders and longevity was a critical factor for the housing associations. For the latter, it was thought to be more important to erect buildings that are cost and quality effective in both the short and long terms. Several interviewees also mentioned the influence of local planning authorities in the decision-making process. Some companies argued that potential for good communication, teamwork and quality would also be influential.

Interviewees in the Oxford Brookes University survey were also asked to estimate the relative importance of a series of issues from the perspective of the people who buy, rent or occupy their homes. For some companies, this was a difficult question, and a few respondents chose to answer the question based on their own personal experience of the housing market. The companies responded that cost, low maintenance and location were amongst what they thought to be the most important factors for their customers. Clearly, this does not agree exactly with the findings of the 'Kerb Appeal' survey described previously. In the Oxford Brookes University survey, brick exteriors and flexibility were not rated as highly. Other factors mentioned were security, privacy, parking, show homes and tenant involvement (for housing associations).

The Market Survey confirms anecdotal evidence that house builders and housing associations are driven both by commercial pressures and to some extent the desires of their customers. Many of the interviewees were interested primarily in being able to offer a quality home to their customers which was speedy and cost effective to construct, but they were flexible and adaptable in the methods and materials they used to achieve these objectives.

The full report from the Oxford Brookes University Market Survey is available on request from BPCF.

A further investigation carried out by John Tebbit as part of a DETR-funded research project on prefabricated masonry systems revealed that professional groups are also interested in speed of erection, a reduction in weather dependent activities and reliable delivery times (Tebbit, 1999). He noted that factors like cost and efficiency were being supplanted by the need for enhanced quality, improved predictability, increased safety and ease of maintenance.

3.4. Other market drivers

This section outlines issues which will also either impel or impede the take-up of precast concrete and other industrialised designs in housing.

3.4.1 'Rethinking Construction'

The report of the Construction Task Force, led by Sir John Egan, on improving the quality and efficiency of construction in the UK, identified five key drivers of change, one of which is integrated processes and teams (Construction Task Force, 1998). The report also highlights performance targets as noted:

- 10% reduction in construction cost
- 10% reduction in construction time
- 20% annual reduction in construction project defects
- 20% reduction in accidents
- 20% increase in predictability
- 10% increase in productivity

Clearly, the use of prefabrication should satisfy the above because it is said to offer faster construction (assembly) times, more reliable production methods and safer working conditions on site, but the Report also highlights the fact the house building industry requires some specific initiatives to move it forward. The constraints of planning and legislation on the housing sector are noted, but the rise in quality of social housing suggests that there is significant scope for the few big customers in this area (housing associations). The DETR has issued a challenge to housing associations to achieve the targets set out in the Egan report by 2004 in order to lead change amongst clients (Martin, 1999b). It is likely that this will result in greater use of partnering arrangements and post-occupancy evaluation to gauge customer satisfaction. Indeed, the Egan Report emphasises the need for clients, suppliers and contractors to work more closely together to achieve improvements in innovation, standardisation, quality and efficiency by implementing:

- Standardised plans
- New component systems
- Trialling of Dutch and Japanese building systems
- Customer care research

Working with Egan's emphasis on reductions in cost and time etc, Ove Arup & Partners have suggested that there are potentially two areas in which the greatest savings can be made (which can both be optimised by using factory prefabrication techniques). Of the costs to build housing, 40% is spent on land, 20% is split between overheads and profit which leaves 40% to spend on the structure (50% is labour and 50% is materials). As it is difficult to reduce material costs, greater savings need to be made from labour and waste. Clearly, factory precast concrete saves labour and reduces waste. The health and safety theme within the Egan Report 'Rethinking Construction' is also relevant. Although the report focuses mainly on efficiency and productivity, it also endorses safe working conditions, which is said to be achieved more easily in a factory than on-site.

3.4.2. Sustainability

An increasing influence on the way housing and all other buildings are procured is sustainability. This term describes a need to undertake to change our current ways of working to conserve resources in such a way that the quality of life for future generations is not jeopardised. Currently, sustainability and its implications for energy, materials, resources and social equity, is beginning to appear in both corporate and legislative documents relating to construction. In the next few years it is likely that a far greater importance will be associated with sustainability and this will impact significantly on how housing is procured. An early example is that the government has sustainability as a priority point on its agenda for the two 'Millennium Villages' at Greenwich and Allerton (Leeds). It can be argued that precast concrete has several advantages in terms of sustainability including:

- Relatively low initial energy costs for production
- High thermal mass
- Reinforcement and concrete can both be recycled
- Can be flat-packed for transport
- Can be designed to be rebuildable
- Can be used on contaminated land

3.5. Use of other materials

There is some evidence to suggest that the level of interest in prefabricated versions of other structural materials as well as concrete indicate a growing awareness and greater willingness to use factory style production techniques in the production of housing. Although there are few examples in the housing market to date, schemes that have been completed have been very newsworthy and volume house builders are continuing to investigate the potential benefits of factory prefabrication.

3.5.1. Steel

Although steel frames' estimated share of the UK housing market is currently less than 2%, it is growing steadily. The UK is 20 years behind other countries in its adoption of steel for housing; in the USA 15% of all new homes use steel. Steel is used in lightweight C or Z sections created from cold-rolled coiled strips. This produces cross-sectional and length accuracy in 'stick', panelised and volumetric constructions, although some commentators suggest the use of sub-frames is particularly useful for housing. Specific benefits of steel frames are said to be improved thermal and acoustic performance over timber or masonry alternatives (Birch, 1999). Westbury Homes maintain that the use of prefabricated steel frames could result in the erection of roof, frame and main structural elements within a day compared to 5-6 weeks of traditional construction (Anon, 1999f; Anon, 1999g). A demonstration 'Surebuild' steel house at Oxford Brookes University has proven instrumental in testing such claims.

CASE STUDY 11

The Peabody Trust Housing Association has employed volumetric steel construction to combat rising construction costs and a fall in skill levels on site. Murray Grove is the first multi-storey (five storey) modular apartments in the UK and uses Yorkon steel modules with terracotta cladding (Blair, 1999; Dawson, 1999; Long, 1999e; Partington, 1999; Pickard, 1999; Spring, 1999b). The first 35 modules were erected in just five days. The fully-fitted out standard steel monocoques are dry-lined with sound absorbing plasterboard and injection insulated and are simply stacked together on site on top of the foundations. Although the project cost 10-20% more than a conventional scheme, this newsworthy design provoked substantial interest in the benefits of prefabrication. Close site supervision was thought to be crucial to the architect Cartwright Pickard, which envisaged prefabrication as a design 'bonus'. The Peabody Trust intends to use prefabrication for future developments in London.

CASE STUDY 12

Britspace MBS has recently completed two demonstration houses in Yorkshire with the Guinness Trust and George Wimpey (Fairs, 1999b; Smit, 1999b). The 80m^2 two bedroom and 96m^2 three bedroom houses use steel modules which come from a production line that can produce up to four houses a day. Although the costs are similar to traditional construction, the system could reduce construction times dramatically (the houses are built in the factory in three weeks and assembled in one week by 12-16 workers). To all intents and purposes the houses look exactly like 'normal' UK homes; each uses 12mm thick brick slips and granite-faced roof tiles. Britspace has also worked in other markets producing fast-track prefabricated fast-food restaurants.

3.5.2. Timber

Timber is another option for prefabricated housing as it is lightweight, flexible and abundant. It has already been used for many motel and hotel buildings in the UK. 8% of all new UK housing uses timber frame construction, including the majority of new homes in Scotland (Gann et al., 1999). Both in the factory and on-site, timber is easily handled and fixed, but the sector has suffered in the past from adverse publicity surrounding its longevity and durability as a building material in frame construction techniques (Smit, 1999a). In recent years, prefabricated timber 'cassettes' for domestic floors have been introduced in an effort to compete with the speed of erection and long-span capability of precast concrete floor units.

CASE STUDY 13

Volumetric claims that its panels and modular timber (and light steel) buildings can be used up to five storeys high, and can create a 40 bedroom hotel in just 15 weeks. It has built 150 hotels so far in the UK alone, and is promoting its capabilities as far as China (Menary, 1998). Volumetric is currently diversifying into housing and has teamed up with contractors Kajima in Leeds and Birmingham to build two CASPAR (City Centre Apartments for Single People at Affordable Rents) projects for the Joseph Rowntree Foundation (Alexander, 2000; Smit, 1999e). The 51m^2 one and two bedroom modules rent for £85-115 per week, and cost £980/m^2 to construct. Kajima maintain that the build costs will come down over time; that, and the residents' satisfaction is indicative that further schemes will follow.

3.6. Summary

This section has focused on some of the broader issues that could affect the take-up of precast in housing. Unfortunately, it is not entirely clear from surveys of the public whether they would or would not prefer traditional construction materials for their homes, but what is clear is that they do associate heavyweight construction with solidity and added value. House builders and housing associations are mostly using precast concrete components, and have not yet fully explored its 2D and 3D potential. However, this trend may reverse in time because the Egan report supports a greater use of prefabricated building methods and sustainability will impact on all construction methods. The relative success of other materials in the prefabricated housing sector is a further indicator of the potential market for precast concrete.

Part 4 - THE FUTURE

4.1 Introduction

The findings of the report are presented in this section. Indications of future growth areas for precast concrete in housing are given in section 4.3, and a series of recommendations are outlined in section 4.4 which will be of interest to anyone involved in the procurement of low-rise housing.

Simple precast balcony units add value to new apartments (courtesy of Belton/Bevlon)

4.2. Key findings

Parts 1-3 of this report explain the use of precast concrete in housing including the issues that need to be considered if its use is to be extended. From this, it is possible to glean several key findings that could shape the future use of precast concrete.

1. The problems of the past can be avoided

Clearly there is an argument that precast concrete has a (historical) reputation which to some extent continues to prejudice its use in housing. The fact that errors in design and construction were made in the past cannot be denied, but the reasons for such problems should not arise again. Many of the 'systems' used in those years were designed to address a short term housing deficit. Design and construction methods are now better understood, and so can be applied in this, very different, period in the history of the use of precast concrete in housing.

2. Low-rise is not high-rise

Indeed, the low-rise housing market should not be considered in the same way as high-rise buildings, but the Egan Report has re-awakened interest in the benefits of factory production techniques, so efficiency and productivity gains from using prefabrication will continue to be investigated and discussed for some time to come. Therefore, there is a need to be clear about the differences between low-rise and high-rise applications for precast.

3. Cultural and perceptual views are critical

There is a significant body of opinion that supports the notion that traditional materials are the most appropriate and popular for new housing in the UK, but there is a growing interest in different styles and ways of living, particular in urban areas. Furthermore, surveys of the public suggest that the UK continues to prefer the security and sellable image of heavyweight construction, and although steel and timber modules are being used, the public seems not to be particularly keen. Reference has been made to European housing practice in this Report; while there are undoubtedly some cultural differences between the UK and EC countries, these differences seem now to be diminishing.

4. The market potential for precast concrete exists
The examples of precast concrete from other EC countries show that there is market potential for the product in housing provided manufacturers promote sensible options to a well-informed market. Although it is valid to seek precedents for widespread use of precast concrete construction from international markets, there are cultural differences that may hinder 'knowledge or technology transfer'. Nevertheless, there are lessons to be learned from countries that use a higher proportion of industrialised housing than the UK.

5. The balance of cost and value needs to be clear
Take-up of precast may ultimately depend on the balance of construction costs and added value. This difficult equation may need to be resolved on an individual project basis, thereby offering every house building client a bespoke package. On the subject of whole-life costing, the question of flexibility (and services flexibility) will be a key factor in satisfying each client's objectives in this regard. With some experts predicting that new homes will have an 'information room' for IT equipment in the near future, housing specifications can be expected to change and reflect such trends. For precast concrete to make inroads in the housing market, contractors and clients need to be made aware of the speed and quality benefits it offers, while owners and occupiers need to be made aware of the performance benefits over time such as thermal mass. It should be noted that a 'first-cost' dominated culture might overlook the potential benefits of precast (e.g. all-weather working and reduction in waste).

6. Precast means innovation in delivery
Clearly, house builders and housing associations have different requirements, so the delivery of service to these groups may be critical. Furthermore, the development of closer working relationships with them will be advisable as the housing market is changing slowly to accommodate more single and elderly people for longer lifetimes. In essence, precast concrete, whether it be components, 2D or 3D volumetric construction, uses principally the same materials in the same places as traditional construction, but delivers them in a very different way.

7. People need to be convinced
UK house buyers regard industrialised construction with some suspicion, but if they were shown how it could fulfil their demands for homes that look 'different but the same', then perhaps this perception would change. The single key activity that would on its own most significantly influence the take-up of precast concrete in housing is at least one demonstration building. This could promote alternative systems and options, explain the design and construction process and act as a reference point for technical, structural, aesthetic, performance, marketing and cultural questions about precast in general (see also section 4.4 for further recommendations).

4.3. Looking to the future

This section considers the generic ways in which precast concrete might be used in low-rise housing and includes some particular examples that are being put into practice in the UK. In Part 1, it was established that there were three basic categories for precast concrete:

- Components
- Panelised construction (2D)
- Volumetric construction (3D)

Although some companies see componentisation as the best option because these are small-scale, easily manufactured, transported and assembled in site, others maintain that volumetric construction enables the manufacturer to add value to the precast, thereby transforming it from a commodity to a product. So, it appears that manufacturers and house builders will approach the future with the view that flexibility in product ranges will provide the best opportunities in the housing market. Indeed, the whole portfolio of precast concrete is as follows:

- Incremental improvement on current components
- Simple, open system of panelised construction
- Integrated (serviced) versions of current components or panels
- More detailed, integrated (serviced) volumetric

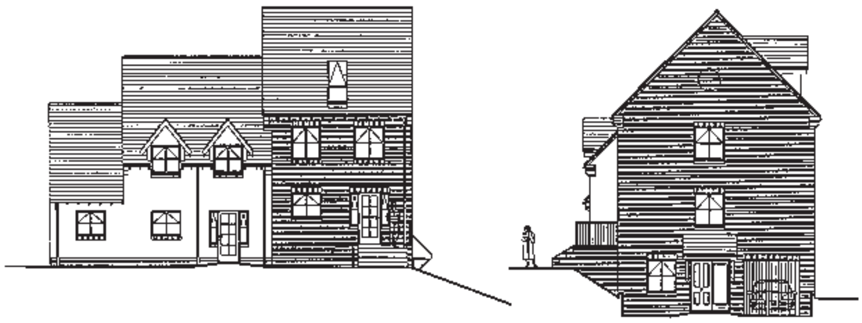
CASE STUDY 14

Ove Arup & Partners recently put forward a proposal to construct a £3-5m+ semi-automated factory to manufacture single storey housing modules in precast concrete (Anon, 1999d; Bolton et al., 1999; Gordon, 1999; Long, 1999a; Pawley, 1999; Spring, 1999a). John Miles, the Head of Arup's Automotive Design Group (and a car designer by training), believes the system of concrete panels will offer factory-built houses at lower costs than traditionally built ones. Concrete has been chosen because of its low material costs and thermal and acoustic properties as well as the ability to stack modules over five storeys high (unlike steel). The 5000m^2, 100 staff factory should be commercially viable if it produces 500 houses per annum; it is designed to produce eight modules per day on a single-shift basis. Six flat concrete panels would be cast simultaneously, then tilted up and their edges joined together. The 8m x 4m modules weighing 25t will be cast and fully fitted out inside the factory in about 33 days. Although transport costs would be an issue (because Arup only envisage one factory would be built in the UK), once on site the modules for two 2-bed houses and a 'brick skin' could be erected in about five days, following installation of a mini-pile and ground beam system. The cost of the completed house has been estimated at between £330-380/m^2 (excluding overheads and profit). Arups claim that the demands of house builders and their customers mean that traditional brickwork is currently the only feasible alternative for the facade, despite their initiatives to use cladding systems.

CASE STUDY 15

A 12 house scheme in Manchester will be the first for an open precast concrete system from Roger Bullivant called 'Quickhome'. Aimed at social housing clients, the Rothwell Street project uses Bullivant's integrated foundation system, this is topped with a precast shell using storey height wall panels that can be faced in brick or any other material.

The envelope can be built in three days, and the system is said to offer thermal mass, airtightness, soundtightness and low maintenance benefits. The houses include an open build skeleton, fixed stair and hollowcore floors. The 180mm thick composite insulated wall panels (of which the concrete skin is 50mm thick) are flat-packed onto site. Cast-in sub-frames are used for openings and the wall panels are rebuildable. A prefabricated timber system is used for the roof. Handover can take place within 15-20 days of commencement.



'Quickhome' typical elevations (courtesy of Roger Bullivant)

CASE STUDY 16

Aire 8100 - the 2nd Millennium Community. A proposal has been made by the Aire Regeneration partnership to redevelop this huge ex-mining community near Leeds using precast concrete houses made in an on-site factory (Anon, 1999a). The idea is that it will produce modular wall elements that cost less because the factory itself is also on site, thus avoiding transport costs. The aim is to produce 3 homes per week, which will result in a reduction in build costs by 19% in the first year, rising to 30% after three years (the total programme is for 5 years). The Aire project will use precast concrete homes on a plot module of 8100mm (hence the name). This will result in an increase in dwelling space of 10% by area and 35% by volume. Homes will have an extended warranty of 30 years. Precast concrete will be used in:

- Foundations - precast concrete system on capping layer designed for future extensions
- External walls - precast concrete with recycled aggregates
- Party walls - precast panels with recesses for wet services in kitchens/bathrooms (sandwich panels between adjacent properties with 100mm insulation).

Proposed cladding options for the project include timber, stone, terracotta and render. The thermal capacity of the concrete panels, high insulation levels and solar orientation all mean that the houses should consume only 1/6th of the total energy used by a conventional house (i.e. <15kWh/m^2 pa).

4.4. Recommendations

The broad remit of this report in bringing together information relevant to precast concrete, the housing market, the construction industry and the public at large, means that recommendations could be also be broad in nature. The impact of the Egan report, of the Urban Task Force, of new planning guidance and of the shifting property markets will all clearly influence the patterns of take-up of new types of housing. However, whilst there is scope to suggest wide-ranging changes, the focus of this publication remains the future for precast concrete in low-rise housing in the UK, in which case there are a number of specific recommendations that can be made.

4.4.1. Testing and demonstration

Evidence that categorically establishes the structural, performance and cost benefits of precast concrete, is of significant value to an industry attempting to prove its worth and compete in a difficult market such as housing. The opportunity to test and demonstrate the application of precast concrete should not be overlooked; a demonstration project can expound the benefits of precast and display confidence. In doing so, both technical and cultural aspects could be addressed. Funding might be sought from industry, manufacturers and the DETR. Such projects might incorporate:

- Component, panel or volumetric options
- Alternative methods of production
- Economies of scope (i.e. offering combinations)
- Partnering with EC companies to adapt standard ranges
- Process improvements

A demonstration project similar to either the European Concrete Building Project at Cardington or the BRE's Integer House can be used to raise awareness of a technique or portfolio of products while also promoting generic solutions. These are good examples of R&D demonstration projects, but another, more public venue for such a venture would be the Ideal Home exhibition. Clearly this would be more likely to reach the house buyers as a target group.

4.4.2. Benchmarking

The variety of products that could come under the mantle of 'precast for low-rise housing' means that producing guidelines or even setting standards could be rather difficult. The by-product of testing and monitoring a demonstration building, as mentioned above, is that generic design and construction guidance may be more feasible. The idea of having an Approved Document for precast is equally suitable: previous ones for timber floors and basements have proved popular. A design standard is another possibility but this is a more long-term issue. Although such benchmarking would obviously increase quality etc, a further result of any such guidance would be to aid the education and awareness process.

4.4.3. Further research

There is always potential to continue to research new, or innovative, solutions, but the real value in further research lies in collaborative projects. It seems that individual manufacturers are keen to continue their own directions in R&D, but there may also be scope to carry out more generic studies on aspects of structure, performance, whole-life costing, rebuildability and process improvement. Non-technical surveys might also be carried out to continue the work described in Part 3. A useful comparison could be made of the views of the public, house buyers and tenants with the opinions of the users of new precast homes, as they become available. A final recommendation for research would be to focus specifically on developing strategies for procurement and service delivery of precast in housing to best suit potential customers.

4.4.4. Education and Training

In the first instance, an initiative could be taken to further educate decision-makers in the benefits of using precast concrete for housing. However, consideration should be given to establishing exactly which stakeholder groups are the key decision-makers, and how best these should be targeted. In order that this effort is not seen simply as a marketing exercise, the involvement of an impartial body such as DETR, the BRE or a University could be sought. The tools to facilitate this education process might include workshops, publications and web pages. Precast manufacturers and the Construction Industry Training Board (CITB) already provide suitable training for factory workers, precast erectors, site operatives and managers.

Safe, efficient erection of precast flooring (courtesy of Birchwood Concrete Products Ltd)

4.4.5. Awareness campaign

In essence, the key may be to raise awareness, to reassure, and to re-establish precast concrete as a genuinely beneficial product for the UK housing market. This may focus on a public relations exercise based on new evidence (provided by earlier recommendations) and assurance of the precast concrete industry's ability to provide an economical, fast, quality product to its customers. There was evidence from the Oxford Brookes University survey to suggest that the housing sector would welcome approaches from precast concrete manufacturers provided they were able to market and supply good quality product that satisfies the demands of flexibility, cost, speed, and visual appearance. However, many were rather reticent about how this could be achieved. So, a refreshed marketing initiative to highlight the potential benefits of precast could be useful. This might include:

- Presenting a series of industry seminars around the UK
- On the road staff to visit house builders
- Developing closer links with customers
- Using IT and electronic product models
- Developing product 'differentiation' e.g. an emphasis on aftercare
- Developing a series of bespoke 'packages'
- Producing generic promotional literature (similar to Belton/Bevlon in the Netherlands)

Appendix 1: Review of European Building Regulations

Introduction

Precast concrete construction is more commonly used for housing projects in some European countries than it is in the United Kingdom. In order to ascertain whether building regulation requirements in Europe are more favourable to concrete, (i.e. making its use easier or rendering other forms of construction less viable) a brief survey of building regulations has been made. This section is based on the Institute of Building Control review of building controls, regulatory systems and technical provisions in the major Member States of the European Community and EFTA countries. The IBCO review was updated in 1998 and covered 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, The Netherlands, Norway, Portugal, Spain, Sweden and the UK. In addition to a document for each individual country, IBCO have produced a Summary document covering all countries. The review provides comparative information on the Building Control systems, including Building Control Law, Building Regulations, National Standards and their status and the Qualifications required for building work. It provides comparative information on the following requirements:

1. Mechanical resistance and structural stability
2. Safety in case of fire
3. Hygiene, health and the environment
4. Safety in use
5. Protection against noise
6. Energy economy and heat retention
7. Access and facilities for the disabled
8. Other requirements

Topics 1, 2, 5 and 6 are of primary interest to precast concrete structures. Where requirements exist for a topic, the specific requirement (i.e. the period of fire resistance or the amount of heat resistance) can vary from country to country. In addition to considering the IBCO Summary, the specific requirements of two countries (Germany and The Netherlands) where precast concrete construction is used regularly have been examined (see also section 1.6 in the main text).

TOPIC 1: Mechanical resistance and structural stability

All fifteen countries have Legislation in the form of Codes of Practice and/or Standards to control structural design, to:

- Prevent actions which might cause stress, deformation or degradation of the works during construction and use
- Prevent collapse
- Prevent deformation or cracking
- Prevent disproportionate damage

TOPIC 2: Safety in case of fire

All fifteen countries have fire resistance stability requirements for walls and ceilings, columns, beams, floors, roofs, stairs and suspended ceilings and criteria for means of escape and fire fighting procedures.

Prevention of initial ignition in installations and systems

There are requirements in respect of the design and installation of heating installations including flues and chimneys in all fifteen countries. There are also flammable gas detection requirements in Belgium, Denmark, Finland, France, Germany and Spain. There are explosion suppression requirements in Austria, Belgium, Finland, France, Italy, Norway and Spain. Austrian, French, German and Spanish regulations include provisions for lightning protection

Limitations of spread of fire and smoke beyond room of origin

There are requirements for compartmentation and separating walls in all fifteen countries. There are surface spread of flame requirements in all fifteen countries and limitation of fire spread on facade requirements in many countries including the UK. There are requirements for fire stopping in all countries except Austria, Belgium and Germany.

Limitation of spread of fire to neighbouring construction works

There are space separation requirements for walls and roofs in all countries except Italy and unprotected areas requirements in all countries except France, German, Ireland, Italy and Sweden.

TOPIC 5: Protection against noise - Requirements for dwellings

Resistance to airborne noise from space outside: requirements in all fifteen countries. There are requirements for the limitation of airborne and impact sound noise between enclosed spaces in all fifteen countries as well as requirements to limit airborne sound from space outside. In the UK, the latter is dealt with by Planning Control rather than by Building Regulations.

TOPIC 6: Energy economy and heat retention: requirements for dwellings

There are requirements for resistance to heat transmission in all fifteen countries. There are requirements for resistance to water vapour transmission in Austria, Finland and Spain and requirements for air permeability of the building fabric in all countries except Belgium, France, Greece, Ireland and Portugal.

Germany

The German Building Regulations are based on model regulations that are written mainly in functional terms and issued by the Federal Government (the Musterbauordnung or MBO). However, the country has 16 Lander which are allowed to make regional variations. The Federal Building Code includes both building regulations and planning law so the building regulations include requirements which are mainly to ensure public health and safety but also include matters relating to the design and layout of buildings and sites. The regulations apply to all buildings and to change of use and to demolition.

The building regulations are supplemented by technical regulations for building products. Technical regulations are set out in lists that differentiate between regulated and non-regulated products. Regulated products generally comply with the technical regulations and suitability for purpose is checked either by the manufacturers certificate of conformity or a certificate of conformity issued by an approved (in accordance with the Federal Building Code or the EC Construction Products Directive) certification agency. Suitability of non-regulated products is confirmed by compliance with general technical approvals, a certificate of inspection and approval or a special agreement for individual cases.

In Germany, the building control system operates through a plan submission, approval and inspection service by the local authority. In the case of low-rise** residential buildings, single storey buildings of limited floor area (maximum $200m^2$), agricultural buildings (max two storeys and $250m^2$) and other non-habitable buildings (max $100m^2$ and two storeys), a simplified regulatory system has been introduced which relies to a greater extent on self certification. Proof of compliance must be submitted.

(** Low-rise is defined as a building in which the floor of any storey containing habitable rooms is not more than 7 metres above the ground at any point.)

Mechanical resistance and structural stability

Structural stability relies primarily on the appropriate DIN Standards for construction methods and the materials used in construction. Eurocodes may also be used; loads liable to act on the works and limits of inadmissible deformation and cracking are given in the Codes.

Safety in fire

Buildings must be designed such that occurrence of a fire and the propagation of fire and smoke are prevented and, in the event of a fire, rescue and the performance of fire extinguishing procedures is possible. Easily flammable building materials must not be used except when they are used in conjunction with other materials that are not easily flammable). The main parts of fire resistant building components must consist of non-combustible building materials except for fire resistant closures in openings. The requirements for fire protection are set out in DIN 4102. Fire resistance requirements are set out in tabular form in the regulations and appear to be broadly similar to UK requirements.

Sound insulation

Buildings must be sound insulated in accordance with their location and use. Technical requirements are contained in DIN 4019. The Standard deals with noise from neighbours, from building services and industrial noise produced in the same building or within a complex. It also deals with traffic noise and from industrial premises which do not form part of the same dwelling. Tables give sound insulation parameters. The figures for airborne sound insulation of walls and floors are the weighted apparent sound reduction index, in decibels (dB) and for doors and windows, the weighted sound reduction index in dB. For floors and stair enclosures the impact sound insulation is the weighted normalised impact sound pressure level, in dB.

The method of sound transmission measurement is different to the UK but the required values are similar, e.g. separating walls 53dB for both countries and separating floors (between flats) 54dB airborne and 53dB impact for Germany and 52dB and 61dB respectively for the UK.

Energy economy and heat retention - requirements for dwellings and residential buildings

More stringent provisions came into force on April 1st, 1995. Although a different method of calculation is used, the requirements appear to be similar to the levels of thermal insulation that came into force in England and Wales in 1995. The regulations have four appendices that describe how the various calculations should be made. Using specifications for heat transmission and air heat losses set out in the provisions, the annual heating requirement (i.e. the heat provided annually by the heating system for the heated rooms of the building) must be within certain specified limits. For small residential buildings, up to two floors and not containing more than three dwellings and for structural alteration work, there are separate 'deemed-to-satisfy' requirements. Allowable heat transmission values in Germany are sufficiently similar to UK values not to have a great influence on the construction method.

The Netherlands

The basis of Dutch law on building work is the Housing Act. The Building Decree (Bouwbesluit) which came into effect in October 1992 contains nationally uniform technical legislation. The main points are;

a) It covers the essential requirements of safety, health, usefulness and energy economy.
b) Requirements are formulated as far as possible as performance requirements and by reference to Standards.
c) Relevant certificates of conformity and Technical Approvals may act as proof of meeting the requirements of the Building Decree.
d) Municipalities cannot impose separate technical requirements. Planning legislation is separately controlled.

The Building Decree is published as 14 independent Chapters covering the technical regulations for construction work and the state of existing construction works. It contains a collection of performance requirements, by which building plans can be tested using measurements or calculations and indicates, through a test value, whether the requirements have been complied with. The builder can decide how to construct and which materials to use providing the performance requirements are met. The Decree refers to Dutch Standards (NEN's) concerning buildings and civil engineering works (Category 'A' Standards). Provision has been made in the Building Decree for Dutch Standards (NEN's) to be replaced by harmonised European Standards (NEN-EN's) as these become available.

Mechanical resistance and structural stability
Standard NEN 6702 refers to the ultimate limit state of the structure. Compliance relating to the ultimate limit state is referred to in accordance with the relevant parts of specific Standards for the type of construction, e.g. NEN 6720 and NEN 6790 for brick or concrete materials. There are specific requirements in respect of collapse in a fire situation whereby the limit state shall not be exceeded within specified time periods

Safety in case of fire
Requirements for fire resistance, surface spread of flame and means of escape are set out in tabular form and appear to be broadly similar to UK requirements.

Sound insulation
There are requirements for the limitation of sound transmission between adjoining dwellings and for the external walls of the dwelling. Detailed requirements are set out in NEN 5077.

Energy economy and heat retention - requirements for dwellings and residential buildings

External walls to habitable rooms, toilets and bathrooms must have a thermal resistance of 2.5m^{2}K/W determined in accordance with NEN1068 (equivalent to a U value of 0.4W/m^{2}K). A maximum total area of 25% of a dwelling or residential building can consist of windows, doors and their frames, providing this area has a thermal resistance of at least 0.11m^{2}K/W (equivalent to a U value of 9.0W/m^{2}K), and an area of 4% which does not need to comply with any thermal insulation requirement. These requirements do not apply if the dwelling or residential building has a thermal insulation index of at least 14 as defined in NEN 1068. The external and internal walls, floor and ceiling of a 'staying area' (similar to a habitable room in UK regulations) must not have a greater air permeability flow rate (as referred to in NEN 2686) than 0.2m^3/s.

Conclusion

It would appear from this study that building regulations in other European countries are generally similar to UK requirements although there are inevitably differences in the way requirements are expressed and the criteria by which they are measured. It would be necessary to carry out a very detailed design and costing assessment to establish the effect of the differences in requirement but it seems unlikely that these would radically influence the method of construction selected. The more detailed investigation of Dutch and German regulations does not bring to light any specific requirement (or lack of requirement) which would be likely to make the use of precast concrete construction more advantageous or economically viable than would be the case in the UK.

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