INTERNATIONAL TRENDS IN CONSTRUCTION TECHNOLOGIES AND THE FUTURE OF HOUSEBUILDING

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This article draws on international evidence on changing construction technologies against the background of future trends in UK housebuilding. There is evidence that housing construction in the UK is inadequate to meet social needs. Major changes in housing finance policy are probably needed to deal with this problem. It is suggested that shortages of traditional skills, together with needs to comply with stringent environmental regulations, may well lead to future housing programmes depending on extensive use of new technologies. Industrialized housing construction techniques have been used successfully in some countries, and the article adduces evidence from this experience. However, in the absence of adequate investment in R&D and training of construction workers, there is a grave danger that industrialized building could result in the construction of poor-quality, expensive-to-maintain housing, as it did in the UK in the 1960s. The utilization of new housing technologies needs to be evaluated in a broad context in order to determine the priorities for R&D, changes in production processes and training programmes.

The materials and components used in conventional house production have changed significantly in the 20th century.[1] But many of these changes have occurred gradually through incremental changes—alterations and adaptations to existing techniques. At the same time, radical changes in technologies have been implemented in attempts to industrialize housing construction.

Since 1967, most of the experience of industrialized building techniques in the UK, has been gained in large-scale commercial and industrial construction, largely in the office boom of the late 1980s. But substantial experience of industrialized

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construction techniques applied to housing as well as to commercial and industrial construction has been gained abroad. This article reviews this experience in the hope that it will stimulate discussion of the role of new technology in housing, and help to guide R&D, construction technology strategies and training policy. There are three pressures which may give rise to the need to reconsider housing technologies: the need to construct high-quality, low-cost housing quickly; the need to meet higher environmental standards; and the potential demand for installation of a wide range of information technologies (IT).

Traditional brick/block construction processes are slow and inflexible. New technologies may offer potential for overcoming constraints on increasing the rate of new construction imposed by shortages of labour with traditional skills. But it may be more difficult to introduce new technology into UK housebuilding than in some other European countries. The profitability of housebuilding is much more volatile in the UK than in France and Sweden, and this makes long-term planning difficult for UK firms and induces conservatism.[2] Nevertheless, the prospect of a low-inflation, high interest rate economy during the 1990s could stimulate UK housebuilders into considering changes in production technologies, rather than relying on profits from exploiting land banks.

Housing shortages, environmental concerns and IT in the home

In 1985, the Inquiry into British Housing[3] classified housing problems into four categories: a housing shortage, reflected in a high number of homeless families living in short-term accommodation such as 'bed and breakfast' hotels; deteriorating housing conditions in the private sector, both rented and owner-occupied; badly designed, difficult to maintain council estates in which ethnic minorities and the poorest tenants were concentrated; and the compartmentalization of housing into sectors and tenures which deny choice, leading to polarization of communities and generating divisiveness and tension.

Two major factors were identified as underlying these problems—a heavy financial bias towards owner occupation and an unhelpful rigid financial and organizational framework. These problems persist and a recent report confirmed that construction of new homes is unlikely to be sufficient to meet social needs.[4]

In the next several years, lower birthrates are likely to result in a sharp decline in the demographic pressure on the housing stock from new household formation. However, other factors such as homelessness resulting from the backlog of shortages, and the likelihood of more people leaving parental homes result in the need for a substantial housebuilding programme. Few typical working households can afford to buy their own homes[5] and studies which have examined the requirements for subsidized housing have shown the likelihood of increasing shortages.[6] The trend to smaller households and people living alone will require an increase in the number of small units. More old people, more single parent families and fewer larger families also serve to make the existing housing stock less appropriate to future needs. The growing proportion of elderly people together with better provision for the disabled will create needs for increases in sheltered housing schemes.[7]

Growing awareness of the impact of buildings on the environment and of the environment on buildings has resulted in tighter energy regulations, and Green Audits. These aim to assess the impact of buildings on global atmospheric pollution, on the local outdoor environment and depletion of resources, the influence of buildings on the health, comfort and safety of occupants and the impact of climate change on buildings. In 1991, the Building Research Establishment launched its third Green Audit aimed at new housing.[8] Such assessments are likely to reveal significant inadequacies in traditional methods of construction.

New energy regulations stipulating higher insulation levels for homes rule out the use of traditional brick/block construction unless additional cavity insulation is used. It is likely that this may be inadequate in future, and the construction of walls using larger blocks and wider cavities to accommodate thicker insulation may soon be necessary. These techniques have been used in low-energy housing, for example, the new halls of residence at East Anglia University. But for such techniques to achieve success on more than a local basis requires reorganization of the construction process and additional skills.

The use of electronic equipment in the home has been increasing rapidly. Large research programmes carried out by leading consumer electronics firms have sustained the pace of change in these technologies, some of which will find application in what have become known as 'smart homes'. While attempts are being made to reduce the impact of the installation of these technologies on the structure and fabric of homes, it is likely that new integrated prefabricated systems may emerge, in which cabling and other building services are installed in factory-made components. One example is the Open Building System developed at the University of Delft in the Netherlands.

Industrialization of housing construction in the UK

Attempts to industrialize housebuilding have occurred in four phases since the mid-19th century. Industrialization began with the standardization of components and was followed by their prefabrication in factories. The third phase included the development of industrialized building systems much used in the 1960s. Studies of the effectiveness of such techniques have shown that while labour time was saved on-site, a considerable part of the labour-intensive finishing of internal work was left to be performed in traditional ways. Major productivity gains were rarely achieved.[9]

The stimulus to use industrialized methods was provided by the need to produce housing after two world wars at times of labour and materials scarcity, and to turn redundant wartime armaments factories to new uses producing factory-made housing. The slum clearance and new town building programmes of the 1960s also drew heavily on industrialized building techniques: scarcity of traditional craft skills and of materials was again an important influence in decisions to use prefabricated systems at almost any cost. The development of industrialized building systems was sponsored by government-funded research during periods of public sector infrastructural investment. Manufacturers played important roles in promoting industrialized systems through the development and marketing of new products and components. Architects of the Modern movement (such as Gropius, Le Corbusier and Buckminster Fuller) introduced factory-made components into their designs influencing generations of local authority architects and planners.[10]

Systems-built apartment blocks

Between 1963 and 1965, UK governments set increasing targets for housing construction and there was concern whether they could be attained in the face of perceived shortages of site labour. Systems building was adopted with the aim of reducing requirements for on-site craft skills by increasing the use of factory-produced components and on-site mechanization. The view was widely held that systems building would rapidly become the dominant mode of housebuilding, especially in the public sector. Industrialized techniques were used extensively in the period 1962 to 1967, especially for the construction of high-rise apartment-blocks.[11] During that period, production of flats exceeded production of houses.

In the early 1960s, many continental systems were examined with a view to use in the UK. Ronan Point, the building which partially collapsed after a gas explosion on 16 May 1968, was one of 26 blocks of flats in Greater London built using one such system—the Larsen–Nielsen. This had been developed in Denmark and used extensively there, although rarely for buildings of more than six storeys: it had been banned above six storeys in the USA. The evidence given at the inquiry after the explosion concluded that the joints holding some of the panels were not sufficiently strong and that there were deficiencies in workmanship and supervision during construction. Furthermore, evidence emerged that system built housing was probably neither cheaper nor quicker than traditional construction. Prefabrication of large structural elements used in 1960s high-rise housing frequently resulted in leaking joints and problems of condensation.[12]

In addition to extensive technical failures, there were growing objections to high-rise flats on social grounds. The pressure of housing need had led to far more families living in such blocks than had been envisaged. The strain imposed on parents and the developmental problems for children were increasingly recognized. This episode reinforced a well-justified prejudice against new technology in construction in the UK. As a result, system-built high-rise flats became discredited and this rejection was reflected in 1967 by the ending of additional subsidies per flat in respect of blocks over six storeys. After 1966, there was a rapid fall in the number of tenders approved for high-rise flats.[13]

Timber-frame construction

Timber-framed construction was traditional in the UK before the 18th century, but brick replaced it as the main form of building. Timber-frame remained dominant in other regions such as North America and Scandinavia which had plentiful timber supplies, and innovation was concentrated there. Modern timber structures are light and can be assembled on site rapidly. The use of timber-frame construction facilitates major improvements in the speed of construction over brick/block methods from 18 to 24 weeks to between five and eight weeks per house.[14] This is achieved because when timber-frames are erected other trades can get on with their work without waiting for bricklayers to finish. The use of timber-frame techniques also encourages the elimination of wet trades indoors. For example, plasterers can be replaced by nailing of standard plasterboard sheets. Once finished, external appearance is virtually identical to that of dwellings constructed traditionally.[15] Shorter construction times also permit housing developers to reduce their site overhead costs and interest payments on capital borrowed, and to meet variations in demand more swiftly.

In contrast, traditional house building is dependent on bricklayers to build up the load-bearing external and internal walls first, with carpenters fixing joists, rafters, floorboards, stairs and door and window-frames after bricklayers have done their work and other trades following carpentry in sequence.[16] For many years, carpentry work has been moved off-site and mechanized increasingly. Timber-frame removes most remaining carpentry work from sites and replaces it with semi-skilled workers in automated factories.

In 1962–63, the cold winter prompted the UK government to set up a commission to study timber-frame housing in other countries, particularly in North America where 30 million had been built since World War II.[17] Changes in government policy away from high-rise to low-density housing in the late 1960s resulted in increased use of timber-frame construction. This method was used extensively in public building programmes until 1976 when public housing construction declined. In this period, about 350 000 timber-framed houses were built in the UK. With the reduction in the public sector market, suppliers of timber-frame materials and components promoted the use of their products with private housebuilders. During the late 1970s, the use of timber-frame increased in private housebuilding, accounting for a quarter of houses built in 1983.[18]

Among the firms building timber-frame houses were some which lacked the necessary expertise. This led to failures which seriously impaired the reputation of timber-frame construction: their proportion of private housebuilding fell substantially by 1984 after bad reports in the press and condemnation in a 'World in Action' television programme. The UK Building Research Establishment identified a large number of faults in design, specification and execution. Common design faults identified included lack of provision for relative movement vertically between the frame and cladding, and failure to provide adequate barriers against fire. Several faults, including poor construction of flashings, gutters and windows, were liable to lead to gross water penetration and the structure remaining wet for long periods. Houses were often not effectively linked to their foundations, ties between walls and sheathings were inadequate and some of the timber in vulnerable locations and liable to rot had not been treated with preservative. Site supervisors had little or no previous experience of timber-frame construction and inspection was inadequate as a result of pressure for speed of construction.[19]

Timber-frame methods have become popular in the growing number of self-build housing schemes sponsored by Housing Associations and Cooperatives. These frames are 'environment-friendly', utilizing replenishable softwoods. Some techniques utilize new methods of insulation such as recycled newspaper blown into cavities.

Questions remain over the suitability of timber-frame construction in the damp UK climate. Risks of condensation have increased in new housing primarily because new, energy-efficient dwellings tend to be more tightly sealed and less draughty. There are needs for safeguards against damp penetration and rot arising from driving rain. Vapour barriers need to be included in designs, made of the right materials and properly installed to prevent interstitial condensation which causes damage to house frames. Good training of site operatives and effective inspection are required to achieve this. While timber-frame construction is inherently economical in traditional building skills, proper supervision and inspection is essential and there is need for special training for site workers to ensure that they understand critical elements in the construction process and meet quality standards. Nevertheless, defects of workmanship on-site occur on both traditional and timber-frame houses because houses consist of thousands of parts put together by teams of workers often in inclement weather.[20]

Recent developments in construction technologies

There are three major trends in construction technologies which affect both the construction process and the product—the buildings themselves. These are: increased use of IT to monitor and control functions within buildings;[21] the use of IT to monitor and control construction processes, including the development of site automation technologies;[22] and the development of prefabricated modular components and new materials. We focus mainly on the development of prefabrication, of which there are two main categories: large modular systems, and smaller component subsystems. There is a widely held view that increasing the amount of prefabrication is the most likely method of improving efficiency and quality.

Despite its chequered history, prefabrication is of growing importance now for several reasons: it is perceived as one of the principal means available to increase productivity on-site and to reduce on-site construction time and costs; increasing sophistication of building components and equipment means that factory environments are often better than sites for their production; and the use of newer techniques—in particular timber-framed housing—offers the possibility of meeting higher standards of energy efficiency. Moreover, techniques used for the production of prefabricated fitted kitchens, bedrooms and bathrooms could be developed to make a wider range of prefabricated products to facilitate more extensive use of prefabrication in future housingbuilding programmes.

Development of prefabricated systems and the pressures to industrialize construction continued after the failure of systems building based on large heavy panels. Industrialized construction is increasingly based on 'open systems' architecture and the modularization of components. Recent developments in factory production methods may facilitate a wider choice of components, increasing the scope for using prefabrication in the assembly of a greater range of housing styles and types.

Prefabrication in office construction

Prefabricated modules were used extensively in the UK office construction boom of the late 1980s to save time and reduce costs. For example, prefabricated toilet modules were used because traditional on-site construction of toilet areas is a notorious trouble spot, giving rise to delays: traditional methods involve the coordination of up to 16 different trades—including wet trades and services trades—in small, cramped spaces. In some projects, trades have had to queue up outside particular areas waiting for their turn to work. In contrast, prefabricated modules are delivered to site fully fitted-out often to very high standards of specification—some are indistinguishable from those produced *in situ*. After they have been plugged into position they are kept locked and sealed to prevent damage and theft until the building is handed over.

The use of prefabricated modules is opening the way for new industries to expand into their manufacture. For example, firms operating in the UK toilet and bathroom module market come from a variety of engineering backgrounds including the nuclear industry, railway coachwork and the temporary accommodations industries.

Nevertheless, British manufacturing and engineering firms which produce modules appear to be slow to innovate. Factory production in the UK is extremely labour-intensive. Firms do not invest heavily in R&D and they have not developed automated production processes. The reluctance to pursue a more innovative strategy is partly due to their concerns over market instability. In addition there is unease in the UK about the appearance of factory produced finishes such as plastic walls.

Intelligent building technologies

At present, most of the effort to apply IT to housing in Europe is driven by firms seeking to create new markets in which they can profit from technologies which they have already developed to meet consumer, industrial and military needs. The technologies which firms seek to adapt and apply include systems for metering and controlling water and energy consumption; a wide range of security systems and infra-red techniques through which electronic equipment in any part of a house can be controlled from wherever the consumer happens to be in the house.[23] While such systems have the potential of offering benefits to residents, for example in attaining a given level of comfort from a smaller expenditure on energy, or in increasing safety in the home for elderly or infirm people, the principal thrust of development and commercialization is to create and meet demands for luxuries, and it appears that market demand is very weak.[24] This drive to use new technology derives from component suppliers' interests in promoting markets for their products, rather than from the aim of satisfying more basic needs for adequate housing.

The use of new technologies outside the UK

French and German designers and contractors have not shown much interest in modular construction, although Germany leads in the production and installation of curtain walling in office construction. It is often argued in these countries that good training and the provision of high-calibre skills means that little can be gained through the use of modularized construction. Nevertheless, curtain walling has been used for housing to a limited extent in France, and this could be indicative of a future trend.

There are, however, numerous examples of the use of prefabricated modules for both commercial construction projects and housing in Scandinavia and Japan. Industrialized construction techniques did not become politically discredited in those countries as they did in the UK after the failures of the 1960s and they are used for different reasons. In Scandinavia, prefabrication is used extensively because the climate is harsh and off-site fabrication is often easier than on-site construction. Scandinavian firms have accumulated considerable expertise in these techniques to reduce the time and cost of installation. For example, in Sweden, modularized lifts were developed in the mid-1980s for use in residential refurbishment work. They are much cheaper than conventional types, and more than 1850 have been installed in the past 5 years.

Many areas of Japanese construction have been industrialized, and Japan relies more heavily on industrialized building to meet housing needs than do European countries.[25] Timber-frame is the traditional method of Japanese house construction practised by small firms using highly skilled craftsmen. While small and medium-sized housebuilders still produce a high proportion of conventionally built wooden buildings, there have been many recent developments to introduce factory produced timber-frames. These take two forms: pre-cut timber-frames and prefabricated panel production. The pre-cut method involves cutting all the joints using computer-numerically-controlled machine tools in factories. Traditionally a carpenter cuts these joints, taking about 30 days per house. The new, automated approach produces pre-cut timber for one house in about three hours. Carpenters then erect these pre-cut frames on site to produce housing which has a similar appearance and feel to those produced using traditional methods. Prefabricated timber panel construction is similar to those used in the UK.

After 1970, the big five housebuilders—Misawa, Sekisui Heim, National, Daiwa and Sekisui Kawa—invested heavily in factory production of houses and sophisticated marketing. Toyota, while it is not a large volume housebuilder, constructs several thousand prefabricated houses per year. The five major housebuilders market to affluent households in urban centres as well as supplying high-density working-class housing. In both markets they use industrially produced and prefabricated parts. These houses are either steel-framed or concrete panel systems. The largest producers manufacture around 70 000 steel-framed units per year—nearly half the total UK housing output. It is possible for up to 90% of each house to be prefabricated in factories, but firms have opted to prefabricate around 55% because this allows greater flexibility in design and style of housing produced. Firms are therefore able to achieve economies of scale through the production of large volumes of standardized components and at the same time benefit from economies of scope—by meeting the needs of a differentiated housing market.

Prefabricated structural frames and cladding are not the only factory produced elements in Japanese housing construction. Prefabricated toilet and bathroom units are also used extensively. These were first used in hotels for the 1963 Tokyo Olympic Games. Their use for housing is growing in Japan, driven by problems in recruiting appropriate on-site construction labour and pressures to save time and minimize complications on-site. In both Scandinavia and Japan prefabricated toilet modules are used extensively in multiple occupancy dwellings. In Japan such units are now being used in both the construction of new detached housing and in housing refurbishment work. In 1973, over 49 000 3-in-1 bathroom units (bath, toilet and wash-basin) were sold in Japan. By 1989 the market had grown to nearly 256 000 units. Between the same years, the number of double units (bath and wash-basin) rose from under 100 000 to more than 846 000 units.

Modules for installation in detached housing include the installation of Jacuzzis, exercise rooms and various microelectronic gadgetry. Growth in these markets is due to product changes which effectively conceal the prefabricated nature of the bathrooms and offer a wide range of styles. The Japanese success in selling up market prefabricated products indicates that the attempt to use industrialized methods to meet extensive needs for housing for rental to people of modest means need not necessarily mean offering them inferior products.

The pros and cons of prefabrication

There are a number of drawbacks to the use of prefabricated housing elements in an industry which is not organized in an appropriate manner to use them and where those involved from design to management and installation have not received appropriate training.[26] For these reasons, many experts believe that the

TABLE 1. FACTORS TENDING TO PROMOTE THE USE OF MODULARIZED CONSTRUCTION

- Improved quality can be secured through factory production in controlled environments. Manufacture, delivery and installation are less dependent upon the weather.
- Faster on-site construction times can be achieved because problems of co-ordinating the work of a large number of trades in small spaces on-site are alleviated.
- The number of operatives on-site is reduced and wet trades may be eliminated. This method of construction is seen to be an advantage when skilled labour is scarce.
- The need to store many fixtures and fittings on-site, prior to installation is eliminated.
- Full-sized mock-ups can be produced in factories to enable testing and problem solving, which, on traditional construction sites can cause delays.
- Greater flexibility in design can be achieved through the use of modular construction if design and construction sequences are changed radically.

TABLE 2. FACTORS TENDING TO RETARD THE USE OF PREFABRICATION TECHNIQUES

- Variations and traditional approaches to design limit the use of modular construction.
- Modular construction requires time up-front for design and off-site manufacture. Units must be designed early and designs cannot be changed without causing considerable delays.
- Space must be left for installation. If installation is delayed it may have adverse consequences for other work on site such as cladding and fitting out.
- Installation problems in plugging in modules may deter their use. For example, tolerances may vary widely between those on-site and those in the factory and design faults may hinder installation.
- Usually it is not possible to store modules on-site, so they must be craned into position at the time of delivery. This requires that manufacturers meet deadlines precisely and that just-in-time management is used.
- Housing buyers tend to be conservative and resistant to modularized components unless final products are indistinguishable from those constructed traditionally on-site.

disadvantages of prefabrication outweigh the advantages. For example, many architects and specifiers do not fully understand what is required to use modular construction effectively. They often assume that units can be bought off-the-shelf, but fail to recognize that adaptations are required to permit installation into a particular building. Alterations may often be of such a magnitude that the units are better treated as bespoke and designed from scratch unless radical changes to other parts of the design are made at the outset.

The use of prefabricated components also has implications for the sequence of construction and therefore may give rise to problems at the interface between trades. Detailed specification is essential if interface problems are to be avoided. An ability to negotiate and resolve problems quickly is needed—installation teams may have to work to tight cranage schedules in much the same way as curtain wall fixers. Furthermore, if these are not observed, damage may be caused to modules during installation. For example, on one Swedish housing site, a bathroom module had been inadvertently placed on top of pipe risers. The pipes had damaged the underside of the module and the floor inside the bathroom. The installation fitters were expected to have the skills necessary to make good the damage.

Tables 1 and 2 summarize the advantages and disadvantages of prefabrication, drawing on the experience of prefabrication as applied to large office projects in the UK, and the experience of construction abroad, particularly in relation to housing.

The need for research

R&D

Evidence presented in this article suggests the need for a coordinated approach to R&D in housing construction. This should involve participants from across the spectrum of those involved in housing production, rather than solely materials and components suppliers, as has often been the case in the past.[27] Developers and Housing Associations making decisions about what houses to build, need to understand the implications of using new technologies, just as designers and construction firms need to know how such technologies will be installed. Users and those involved in building maintenance should be consulted on operation and maintenance. It would be unwise to wait for demand to rise rapidly before a thorough evaluation of choice of technology is made. The consequences of using untried and untested techniques may be failures similar to those experienced in previous attempts to rapidly implement industrialized housing techniques.

Construction process reorganization

The use of industrialized housing techniques has major implications for the organization of the construction process, both internally—within each firm, and externally—between firms. Firms need to understand how to change their internal structures to work in new ways: new relationships between different firms may result in different competitive pressures and industrial restructuring which the traditional building industry may be ill equipped to cope with. Industry organizations such as those representing housebuilders should prepare their members to face up to the changes which may well occur in their industry over the coming decade. Failure to change may result in wasted opportunities and the adoption of techniques which firms are incapable of using.

Training

Perhaps the most pressing need within housebuilding is to modernize the industry's skills. Construction depends on a supply of highly skilled operatives to provide flexibility across a multitude of tasks in different types of work. Throughout the 1980s construction workloads were concentrated in the South East of the UK: in 1989, 41% of construction work was carried out there. During the mid- and late 1980s there appears to have been a substantial migration of construction labour—particularly from the North—into the booming South East. Skill shortages were experienced during the 1980s' boom, indicating a failure to plan training programmes to meet demand for skilled workers. Two aspects of the problem were evident:

- too few skilled workers were trained and given sufficient incentives to stay in the industry.
- skill needs changed and many of those in the industry were no longer equipped to carry out the tasks required. Building defects and construction accidents provide evidence of carelessness and inadequate skills.

Construction employment fluctuates more or less in accordance with fluctuations in the economy as a whole. But employment in particular occupations also fluctuates with the changing composition of construction output. Between 1974 and 1988, a decline in employment in construction has been accompanied by a shift in sectoral composition and occupational structure. The major growth sector in the mid-1980s was office construction of which a high proportion was based on prefabrication. For example, the widespread use of curtain walling eliminated the need for brickwork on many large projects and this reduced the demand for bricklayers and increased the demand for cladding fixers. Traditional housing construction methods are intensive in the use of skilled site labour such as bricklayers and plasterers, but employment of bricklayers fell by more than 30% and plasterers by nearly 25% in the period of 1974 to 1988.[28] Any major attempt to expand new housing construction based mainly on traditional construction methods could therefore be liable to be severely constrained by shortages of craft skills, in particular of wet trades such as bricklaying and plastering.

One of the principal attractions of industrialized housebuilding is that its use may reduce the need for scarce skilled site labour by combining factory production of components and sub-assemblies with less skilled assembly workers on-site. But workers assembling prefabricated housing need some training, including technical knowledge even if the need for traditional manual skills and intuition is less.[29] Failure to ensure that appropriately skilled labour is available could lead to catastrophic failures as it has in the past.

Housing will need to be 'engineered' to a greater extent in future if it is to be able to meet stringent energy and environmental requirements. The Chief Executive of Barratts has been quoted as stating that it would take 10 years for UK housing to reach current Swedish standards in these respects because it would take that long to train the workforce to the requisite standards.

Conclusions

Major changes in technology require huge investments and it is important that the correct choices are made. In the short term, it may be sensible to use up existing stocks of materials. For example, it has been estimated that sufficient bricks are available in stockpiles now to build 170 000 houses.[30] But if the attempt were to be made to expand housing production using only traditional methods, the rate of construction would be tightly constrained by shortages of skilled workers. The continuing decline in the number of people receiving construction training needs to be remedied. At the same time a new approach to housing construction technologies should be found to provide a 'middle way' between out-of-date traditional techniques and fully industrialized production which is unlikely to be viable. R&D, new training programmes and changes to the organization of production must be implemented to ensure that problems experienced in previous use of industrailized construction do not recur in the future.

It is likely that housebuilding to meet social needs will expand in the next few years. Because of the need for energy saving and shortages of traditional wet trade construction skills, the use of industrialized methods could grow. Undoubtedly, pressure for energy conservation will increase and Green Audits will spread and new technologies offer greater scope than traditional methods for meeting such requirements economically. But in the absence of major organizational changes, the use of new technology may not result in cost savings. Indeed, reviewing the history of the 1960s, Finnimore concluded that the system building of the time was generally less productive than traditional methods.[31]

Investment now by government, industry organizations and by firms in the sectors likely to be involved in large scale provision of housing has a high probability of pay-off. Failure to make such investments is liable to result in increasing import penetration of prefabricated components, as was experienced in the office construction boom of the 1980s.[32] Strategic decisions need to be taken soon about which prefabrication techniques are likely to be most suitable and about their implications for the organization of construction processes and for the need for new training programmes.

Office construction draws upon an almost entirely different set of resources of components, techniques and skills from traditional house production—the industries are in many ways quite separate. Further research is needed to assess the possibilities of transferring the knowledge gained in industrialized construction of offices, and the potential for adapting it to meet the needs of future housing construction.

Notes and references

1. National Economic Development Office, *Strategy for Construction R&D* (London, NEDO, 1984), pages 6 and 7, illustrate a wide range of changes between houses built in 1935 and 1985.
2. J. Barlow and A. King, 'The state, the market and competitive strategy: the housebuilding industry in Britain, France and Sweden', *Environment and Planning*, forthcoming.
3. *Inquiry into British Housing: The Report* (London, National Federation of Housing Associations, 1985).
4. Joseph Rowntree Foundation, *Inquiry into British Housing, Second Report* (London, Joseph Rowntree Foundation, 1991).
5. G. Bramley, 'Meeting housing needs' (Bristol, SAUS, University of Bristol, 1989).
6. Eg, see M. Kleinman, 'A decade of change: providing social housing 1980–1990', mimeo report to Joseph Rowntree Foundation, 1991; S. Wilcox, *The Need for Social Rented Housing in England in the 1990s* (London, Institute of Housing, 1991).
7. Centre for Strategic Studies in Construction, *UK Construction Prospects 2001* (Reading, University of Reading, CSSC, 1990).
8. Building Research Establishment, *BREEAM/New Homes, Version 3/91: An Environmental Assessment for New Homes* (BRE, 1991).
9. B. Finnimore, *Houses for the Future* (London, Rivers Oram Press, 1989).
10. M. Bowley, *The British Building Industry: Four Studies in Response and Resistance to Change* (Cambridge, Cambridge University Press, 1966) page 77; R. McCutcheon, 'Technical change and social need: the case of high-rise flats', *Research Policy*, (4), 1975, pages 262–289; R. B. White, *Prefabrication: A History of Its Development in Great Britain* (London, HMSO, 1965).
11. S. Merrett, *State Housing in Britain* (London, Routledge and Kegan Paul, 1979), page 89.
12. B. Russell, *Building Systems, Industrialisation and Architecture* (London, Wiley, 1981), pages 446–455.
13. Merrett, *op cit*, reference 11, pages 130–131
14. A. Cullen, 'Speculative housebuilding in Britain: some notes on the switch to timber frame production methods', *The Production of the Built Environment*, 3 (London, Bartlett School of Architecture, 1981).
15. M. Ball, *Housing Policy and Economic Power: The Political Economy of Owner Occupation* (London, Methuen, 1983), pages 185–188.
16. It is not strictly accurate to describe brick/block housing construction in the UK as 'traditional'. While the skills required in construction have changed little, new materials in the form of lightweight blocks are used extensively. It is as yet unclear whether any long-term problems may occur due to the utilization of these materials.
17. 'O' Farrell timber frame housing', *Construction News Magazine*, March 1982.
18. D. M. Gann, 'The political economy of timber framed house production' (Brighton, SPRU, University of Sussex, 1984), page 27.
19. 'Timber frame houses "potential disaster"', *The Guardian*, 31 April 1985.
20. National House-Building Council, *A Review of the Evidence about Timber Frame Dwellings* (London, NHBC, 1983); Association of Metropolitan Authorities, *Timber Frame Housing—A Cautionary Note* (AMA, September 1983).

21. D. M. Gann, 'High technology buildings and the Information Economy', *Habitat International, 14* (2/3), 1991.
22. D. M. Gann, *Technology Change and Construction Skills in the 1990s* (CITB RRO5, 1991).
23. European Conference on Integrated Home Applications, Amsterdam, 13–15 January 1991.
24. D. M. Gann, 'High technology buildings and the Information Economy', *Habitat International, 14* (2/3), 1990.
25. There are special reasons for this, for example there is a shortage of land in Japan and much of the old stock is very small and inadequate. It is often only possible to build on existing sites and frequent rebuilding is undertaken, for example to house a family as it expands. The need for frequent rebuilding encourages the use of prefabrication in an economy where construction labour is scarce. The average life of a Tokyo house is 18 years.
26. Large Japanese housebuilders have their own schools to train erection teams and subcontractors who must pass a test before they can work on site.
27. IPRA, *Construction R&D*, report prepared for the Construction Policy Directorate, Department of the Environment (Brighton, Innovation Policy Research Associates, 1992).
28. D. M. Gann, *Future Skill Needs of the Construction Industry* (Brighton, Innovation Policy Research Associates, 1991).
29. Moreover, much of the UK's housing stock is ageing and will need extensive maintenance and improvement during the 1990s. This will increase the demand for multiskilled maintenance operatives.
30. This stock also represents a considerable investment in embodied energy which should be calculated in any 'green' assessment of housing production. *The Guardian*, 25 January 1992.
31. Finnimore, *op cit*, reference 9, page 238.
32. In the case of curtain-walling for office buildings, components were imported and workers from overseas with the specialist skills necessary to assemble and install them were employed.