Prefabrication and Sustainability in UK Housing

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ABSTRACT

UK housing is undergoing change. There is a concern about site-based, mainly masonry methods of construction and their ability to meet increasingly demanding standards of performance and quality and the availability of suitably trained labor. Although site-based construction can be efficient and of high quality, there are inherent difficulties in management, quality control, and efficiency due to the number of unpredictable factors such as weather, management of subcontractors, and scheduling issues.

Moving more of the construction process from the building site, where in the UK efficiency is often low and management difficult, into the relative safety of factory conditions, where efficiency and control can be better managed, has the potential to lead to significant improvements in both the quality and speed of construction compared to traditional site-based construction. This can lead to significant sustainability improvements. The technical benefits may include increased speed of production, reduced levels of defects and waste, greater efficiency in the production process, and reduced impact on the environment. This can also lead to social benefits including improvements in health and safety, more stable employment, and investment in machinery and development of skills. Greater stability in the manufacturing process also generates potential economic benefits.

All of these contribute to the environmental, economic, and social impact of the industry. This paper considers the growing relevance of prefabrication to the UK housing industry and discusses the sustainability benefits that may result from a move towards more off-site fabrication.

THE UK HOUSING MARKET

To achieve housing renewal on a 100-year cycle in the UK, a construction program of between 225,000 and 250,000 homes annually is necessary. In addition, government predictions of household growth suggest a further three million new dwellings will be required by 2016. Yet house building in recent years has fallen to its lowest level for many years with just 166,400 new homes completed in Britain in the year 2000. Excluding the wartime period 1940-1946, completions are at their lowest since 1924.

Current replacement of old housing is minimal, with most new housing adding to the stock rather than replacing old, outdated housing. Just within the social housing sector, it is estimated that from 2000 to 2016 one million new dwellings will be required. These are expected to be mainly high-density, terraced houses and purpose-built flats.

This demand for new housing presents a significant challenge to the UK construction supply chain with its diminishing labor force and increased business performance demands, leading the industry to reconsider off-site methods of construction and to investigate other ways of building homes. The need to raise output per operative and to use resources more efficiently through the application of research and development in new housing technologies is vital if the industry is to meet society's demand for new housing. Unfortunately, this has not been achieved, and construction has fallen considerably behind manufacturing in the past 100 years.

"A family house at the beginning of the 20th century cost approximately the same as a family car. By the beginning of the 21st century, the ratio between the two was approximately 5:1" (Ashworth and Hogg 2000)

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SUSTAINABILITY

In addition, concern is growing about the impact of the additional three million new homes on the environment, infrastructure, and local communities. Catalyzed by the Rio Earth Summit and concerns about humanity's relationship with nature and its effect on the natural processes of the earth, sustainability has emerged in recent years as a major international issue for the twenty-first century. The search is for balance between the social, economic, and environmental impacts of human activities. Sustainability offers the prospect of a holistic response to the present environmental and social crises and makes much needed connections between nature, culture, economics, politics, and technology. This is beginning to induce clients to consider the sustainability impacts of how we build, operate, and maintain our buildings. For example, the Housing Corporation, which funds much social housing, now requires an increasingly high standard of Ecohomes (BRE 2000) environmental rating for all housing schemes they finance.

PREFABRICATION INDUSTRY

In the UK following 1945, there was an organized drive for the mass provision of (mainly social) housing. Sponsored by successive governments, various schemes included industrial building methods leading to experimentation and investment in various off-site building techniques, such as large panel concrete construction. Many of these projects subsequently suffered technical and social problems and in the last quarter of the twentieth century there developed considerable mistrust and a perceived market resistance toward prefabrication, particularly in residential construction, influenced by past errors in design and construction. The problems included inappropriate technologies that led to moisture penetration, condensation, and mold growth and sometimes even structural problems, such as at the Ronan Point disaster where a minor gas explosion led to a major structural collapse of one corner of a 23-story block of apartments. However, many of the problems were social in nature, caused by inappropriate forms, such as tower blocks for young families and broken lifts denying access to the elderly. All this created a distrust for new technology despite examples from home and from abroad illustrating its technical feasibility.

Thus, changing the way the UK building industry works—from a craft base, using tried and tested organizational techniques, albeit sometimes formulated in the nineteenth century—is a considerable challenge. Nevertheless, the use of off-site fabrication methods has received a great deal of attention in recent years; the trend began with the hotel sector, where quality and repeatability of units lend themselves to volumetric buildings, and this technology is now being increasingly applied to apartments, houses, and sheltered accommodation.

However, today the increased interest in industrialization in UK housing is not driven by ideology but by practical issues. It is well documented that the building industry has been fragmented, partly as a response to historic variable supply and demand market conditions. Recently, government-sponsored reports by the Construction Task Force, *Rethinking Construction* (Egan 1998) and *Accelerating Change* (Egan 2000), have made clear that the construction industry must change its way of working if it is to survive and satisfy market demands for better quality, faster construction, and better cost control. They have challenged the UK construction industry by setting demanding targets for improved performance and efficiency. The reports highlight the fact that a lack of traditional skills, a diminishing labor market for site work, economics of mass production, on-site health and safety issues, demands for higher standards, and increasing regulatory requirements, such as thermal and acoustic performance, are leading the industry to reconsider which technologies are most appropriate for house building.

Today the UK enjoys a relatively stable economic construction environment amenable to the capital investment necessary to develop factory-building techniques. All these factors have led to a greater interest in off-site manufacturing technologies, partly fueled by the government demand that, from 2004, 25% of publicly funded, social housing use "modern methods of construction" involving some off-site manufacture. Many house builders are currently investigating a variety of innovative ways to build dwellings. Advanced industrialized buildings in the form of factory-prefabricated elements or full three-dimensional units are increasingly demonstrating that these are appropriate forms of construction to achieve quality, cost, and time targets.

PREFABRICATION SYSTEMS

In the UK, there are three principal approaches to off-site production of residential buildings currently being used.

Figure 1 *A volumetric production line.*

Figure 2 *A volumetric housing scheme under construction in London.*

Volumetric Systems

Three-dimensional units are manufactured in the factory with a high degree of services, internal finishes, and fit-out installed in controlled, factory conditions prior to transportation to site. This approach is particularly suited to highly serviced areas, such as kitchens and bathrooms, which have a high added value and cause disruption and delays on site but may be less appropriate for other rooms that have less internal fit-out. The benefits include improved quality, reduced defects and snagging on-site, increased speed of construction on site, better working conditions, increased predictability, and efficiency in the production process. A disadvantage is that each unit has to be transported separately, and the maximum size of the unit is determined by the practical problems associated with transportation by road.

Panellized Systems

Flat panel units are manufactured in a factory and fixed together on site to produce the three-dimensional structure. Services, windows and doors, internal wall finishes, and external claddings can potentially be installed in the factory, although this is currently rare in the UK. Panellized systems are more flexible and can more easily accommodate variations in unit plan and detail design than volumetric systems and can be stacked flat, so more of the structure can be transported in one journey, reducing transport impacts. However, the levels of finish and services that it is practical to install into panels prior to shipping to site are reduced compared to volumetric systems.

Figure 3 *Light steel frame panellized construction.*

Hybrid (Semi-Volumetric) Systems

Volumetric units are used for the highly serviced areas such as kitchens and bathrooms, and the remainder of the building uses panels or some other means of construction. This offers the opportunity to remove the highly serviced areas from the critical path of the project and potentially bring together the benefits of different volumetric and panellized systems. It can also address the issues of providing flexibility and consumer choice. A kit of parts can be used to provide flexibility yet maintain the benefits of standardization.

SUSTAINABILITY BENEFITS

How can the move toward off-site fabrication and away from traditional masonry construction lead to sustainability benefits and reduce the negative impacts of the additional three million homes? Recent reports (CRISP 1999) have identified considerable areas of overlap between the agenda of improved industry efficiency through prefabrication and partnering and the sustainability agenda, and there are specific potential benefits that prefabrication can offer.

Site Benefits

The key feature of prefabrication is that some of the process is removed from the site to controlled factory conditions. The amount of site work will vary depending on the prefabrication system used, which will affect the potential site benefits. Reducing the amount of time spent on site leads to less detrimental impacts on the locality. Experience in the UK shows that prefabricated hotel buildings can be constructed on site in half the time (or less) of a traditionally built hotel of a similar size, and this could be reduced further with the use of factory-applied claddings. In the catering industry, clients have claimed a factor of 10 improvement in construction and commissioning time scales for a typical fast food restaurant

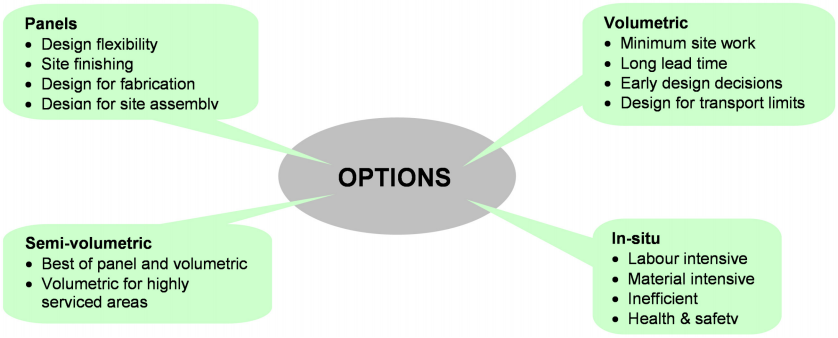

Figure 4 *Features of prefabricated housing.*

when using volumetric construction. This means that the locality around the site is disrupted for a shorter period, reducing noise, pollution emissions, and local traffic disruption. In addition, the lightweight nature of many of the buildings (compared to masonry construction) can often result in smaller foundations and therefore less groundwork, also reducing local disruption as well as reducing the volume of materials used in the groundwork and spoil to be removed.

Furthermore, prefabrication generally leads to fewer deliveries to site compared to traditional construction methods. Monitoring of a site in London suggested that deliveries to a volumetric site were reduced by up to 60% compared to a similar building nearby using traditional construction methods. This also reduces local disruption, although volumetric sites generally have larger vehicles delivering bulky, awkward volumetric units that require cranes to off-load. Thus, careful management is required to ensure minimum disruption when deliveries are made.

The wider transport implications of prefabrication are difficult to measure. Volumetric deliveries often come from considerable distances from the factory. However, there are generally fewer deliveries than with traditional construction. In addition, the shorter period on site and the nature of the work means that less labor is required at the site and for a shorter period. Panellized construction can be more efficient in delivery to site, but more subsequent work on site to finish the building off can lead to additional transport movements. In general, it is likely that a well-managed site using prefabricated components can significantly reduce the impact of transport.

For a full transport analysis, the additional transport movements related to the factory should be considered. However, the workforce in a factory is more likely to be local than at a building site, and thus will travel shorter distances, and is more likely to use public transport, where possible. Also, material deliveries to a factory are usually planned so that full loads are delivered and local suppliers can be used.

Process Benefits

The management of the construction process has been identified as a particularly important area, and the interaction of the prefabricated components with site processes, such as foundations, service connections, and cladding, are critical. It is essential to consider the process of manufacture and assembly when considering the building design stage. Technical decisions can lead to process problems, and so both must be considered together.

A building site does not provide an ideal environment for achieving quality construction or safety. Construction work on site can be a dangerous activity and lead to significant numbers of casualties and fatalities. More demanding health and safety requirements are pushing many builders to consider off-site manufacturing techniques. Moving much of the process into more controlled and comfortable factory conditions enables safety requirements to be more easily met and policed, and healthy and comfortable working conditions are more readily maintained. This also helps with attracting and retaining a high-quality workforce, who are increasingly hesitant to work at inhospitable and often dangerous building sites. Conversely, the use of heavy lifting equipment to locate the prefabricated components on site requires careful management.

The use of scaffolding is a particular safety concern. Some schemes in the UK have tried to eliminate the need for scaffolding completely by integrating claddings in the factory. The perceived market preference for brickwork is seen by many as a potential obstacle for further off-site manufacturing. Nevertheless, several companies are developing options for alternative claddings to traditional brickwork, with improved detailing that avoids the need for scaffolding, and some of these can be installed in the factory. Many UK schemes using prefabrication use alternative cladding systems, such as cedar boarding or polymer-based renders.

Resource Benefits

The UK government has recognized the importance of resource efficiency within a sustainable development policy in its recent report, *Quality of Life Counts—Indicators for a*

Strategy for Sustainable Development for the United Kingdom (DETR 1999):

"In the past, focus has centred mainly on improving labour productivity. In the future, greater emphasis will be needed on resource efficiency. We need to break the link between continued economic growth and increasing use of resources and environmental impacts."

For construction this means focusing on construction processes that use material efficiently, minimize waste, and reduce reworking. It is estimated that between 13% and 18% of materials delivered to UK construction sites are wasted and never used properly.

Manufacture in a factory allows far better management of the resources and the waste stream, with more efficient use of materials and ordering of exact amounts, more careful storage, and the possibility of design to suit standard sizes. In addition, any waste that occurs can be more easily collected and reused or recycled. Many off-site manufacturing plants have recycling facilities installed, as this reduces the costs of disposal of waste. There is further potential for reducing waste when using prefabrication if the designer is prepared to coordinate sizes so that materials such as timber and gypsum sheets are used in their standard sizes without generating many off-cuts.

In addition, volumetric construction allows buildings to be potentially dismantled and the modules reused at a different location. Modular hotels in the UK have been dismantled and removed to a different location when found to be uneconomic at their original site. Traditionally, many volumetric buildings were used as temporary buildings and removed for reuse when no longer necessary. Thus, the technology for reuse is well established. Many of the materials used in this type of construction, such as the steel framing, can also be extracted for recycling at the end of the life of the module. This is made easier by the lightweight, dry construction methods that are generally used. This is likely to become more significant in the future when EEC legislation about producer responsibility encompasses the construction industry.

Furthermore, building sites are also notoriously inefficient in the use of labor and materials. Studies in the UK have shown that site-based activities have a considerably lower efficiency in the use of labor than factory-based activities. It is estimated that up to 30% of construction work is done to correct poor workmanship or design. Furthermore, site labor is being managed at 40-60% of potential productivity, given the level of technology employed (Egan 1998). Inspection and quality control systems in factory production offer the potential to considerably reduce workmanship issues, although any site-based finishing may need close supervision. Anecdotal evidence from volumetric hotel construction suggests that many quality control issues can be considerably improved.

Life Span

The design and construction of housing must ensure that the resulting buildings adequately address the needs of the householder with regard to emotional satisfaction, function, and economic performance; otherwise the buildings are likely to have a short lifespan. With both prefabricated and standardized construction, it is vital to remember that the likely lifespan of such housing is an important factor in its sustainability.

Long-lasting buildings that are flexible, adaptable, and can be easily upgraded reduce the need for demolition and replacement with all the ensuing demands on resources and subsequent impacts. Past mistakes concerning a lack of quality, attention to detail, and consideration of the life cycle must be recognized and addressed. One of the perceived problems of prefabricated building systems from the 1950s and 1960s is that they are less durable than "traditional" masonry construction, although this may be partly to do with management and maintenance programs than inherent in the technology. Any perception of a link between prefabrication and nonpermanence may be a limiting factor in the adoption of the technology.

At present it is unclear how durable the new prefabrication technologies will be and, just as importantly, how flexible they will be to changing demands and new technologies that will emerge during their lifetime. However, prefabricated and standardized construction methods provide reliable, tested, and flexible tools with which the design team can work to satisfy occupant demands and allow upgrade of services and flexibility of layouts that can be integrated into the basic design. The prefabrication process also offers the potential to assemble and weatherproof components in dry conditions, thus avoiding exposure to moisture. Site-based construction often leads to exposure of structural elements to moisture over a period of several days, which is then often trapped by the cladding, leading to potentially accelerated deterioration affecting the lifespan of components.

Improved Quality of the Final Product

Clients of the house-building industry are generally expected to put up with a considerable amount of snagging, making good, and other fault remedying that is common when a new house is completed. Yet as a society we have high expectations of reliability and fault-free performance from factory-made products such as televisions or cars and do not tolerate problems with these products. A culture of acceptance of faults and poor standards of completion and commissioning has grown up in house building, which would be totally unacceptable in virtually any other industry.

Factory-based activities provide the opportunity to address issues of quality and fault finding by using better quality management including testing and checking procedures that are more easily implemented in the factory before components are delivered to site, thus reducing the opportunity for faults. For example, volumetric units can have electrical and water installations fully tested prior to leaving the factory. Anecdotal experience in the UK suggests that far less callbacks are necessary to make good defects after completion for buildings using a significant amount of prefabrication. This is

a significant cost and efficiency benefit to the builder and leads to satisfied customers. It also reduces wastage of resources.

Furthermore, moving work off site also leads to quality benefits that result from better working conditions, which make it easier for work to be completed to the required standard. For example, the correct and careful installation of the elements of the fabric—in particular, insulation materials and air barriers—is important to the thermal and acoustic performance of the building in use. Thermal and acoustic performance is very dependent on the quality of workmanship and supervision. Factory manufacture allows operatives to be better trained and supervised in these tasks and allows regular checking and testing of performance. Problems such as omitted insulation and badly fitted air barriers are less likely to occur.

Benefits to the Workforce and Community

Building sites are temporary employment locations, so they generally offer little long-term amenities for the local community. Manufacturers in factories are often closely linked with the local community, with much of the workforce coming from the locality. They provide a long-term economic and often social service for the community. Many manufacturers of prefabricated modular or panel units in the UK are well established in particular locations and have developed a highly trained, local workforce and strong links with the local community.

Employment at a factory manufacturing prefabricated building components is generally more stable and long term than site-based employment, which is intrinsically transient. As a result, factory-based employers are generally more willing to invest in training for their workforce. Furthermore, to function efficiently, prefabrication requires high levels of skill and flexibility in the workforce. This necessitates greater training by employers. From a financial point of view, the shorter construction period allows a quicker return on investment by the client and reduced overhead costs.

CONCLUSIONS

There is a climate of change in the UK residential construction sector driven by government policy, the demands of financial investors, increasing quality standards, more demanding regulations, health and safety issues, and a lack of traditional site skills. House builders are being driven to improve standards of quality, performance, and efficiency, and this is leading to an increasing interest in new construction methods including off-site manufacture.

There is an established sector of the construction industry manufacturing volumetric units for hotel construction, key worker accommodation, the education sector, and budget restaurants. The economics of this type of construction relies on repeatable units so that large production runs can be set up. A figure of 40 repeatable units (of similar size and layout) is sometimes quoted as a minimum number required for such systems to be cost competitive. The volumetric manufacturers have developed technical systems and construction processes to maximize the benefits of this type of construction. Panellized systems are more commonly in use in UK housing but with relatively little finishing-off of the panels in the factory. Several builders are looking to move toward significantly more integration of finishes in the factory.

The objectives of sustainability and the agenda of improving efficiency in construction overlap in several areas, notably waste minimization, process integration, a commitment to people, and a quality-driven agenda. Prefabrication offers an opportunity to address these agendas and improve both efficiency and sustainability. However, the industry has much to learn to fulfil the potential of this technology, and house builders are only just beginning to explore and utilize this technology.

As clients are increasingly demanding improvements in the process of manufacture as well as the performance of the final product, the housing industry will need to take sustainability issues far more seriously. Prefabrication offers a variety of potential benefits, but it will depend on how this technology is developed and used as to whether these are realized.

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