Housing in the natural city: The role of prefabrication

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Introduction

There is increasing concern about site-based methods of construction and their ability to meet the needs of modern, 21st-century cities. Issues of quality, the availability of trained labor, high energy performance, and other sustainability issues such as efficient materials use, health and safety on site, disruption to the community, and increasingly demanding performance and quality standards, are leading to a rethinking about how to build in the future. Although site-based construction can be efficient and achieve high quality, there are inherent difficulties in management, quality control and efficiency, particularly on large sites, due to the number of unpredictable factors such as weather, management of subcontractors, waste, disruption and scheduling issues.

Off-site manufacturing processes, with industrialized production techniques more akin to automotive or shipbuilding, have the potential to lead to benefits in efficiency, speed, quality and control in construction. Such technology offers considerable potential to improve the way buildings are designed, use resources and create healthy, stimulating, and comfortable spaces. Potential social and economic benefits include improvements in health and safety, more stable employment and investment into machinery and development of skills. Environmental factors such as transport of materials and labor to site, processes used on site, materials used, waste created, resource efficiency, pollution emissions and local disruption may all benefit from this technology.

But can prefabrication lead to regional responses, where standardized components and processes lead to a variety of solutions appropriate to the region and individual site? This may be the true test of how well off-site manufacturing technology can contribute to sustainability. Can the technology of mass customization lead to appropriate solutions that respond to site conditions and regional climatic and cultural requirements?

Sustainability

Environmental degradation in cities is not new, as can be seen from this description of London by Evelyn in 1661: "... her Inhabitants breathe nothing but an impure and thick Mist, accompanied with a fuliginous and filthy vapour, which renders them obnoxious to a thousand inconveniences, corrupting the Lungs, and disordering the entire habit of their Bodies; so that Catharrs, Phthisicks, Coughs and Consumptions, rage more in this one City, than in the whole Earth besides" (EVELYN, 1661).

But the global scale of development presents major challenges, as this quote from Gro Harlem Brundtland, on the issue of sustainable production and consumption patterns at the Symposium: Sustainable Consumption in Oslo in January 1994, suggests: "... it is simply impossible for the world as a whole to sustain a Western level of consumption for all. In fact, if 7 billion people were to consume as much energy and resources as we do in the West today we would need 10 worlds, not one, to satisfy all our needs" (BRUNDTLAND, 1994).

In reality, the sustainability debate is very much about the old truth that *the poison is the dose*. The earth can sustain small numbers of human population consuming and polluting to western levels, or larger numbers but with a far more ecologically appropriate lifestyle. But it cannot absorb 7 or 8 billion people all wishing to have a western lifestyle. Thus, sustainability is about balancing population numbers with the level of resource use and pollution, and if we do not recognize this fact, then the truth is likely to be forced on us by the very real limits of the earth to provide resources and absorb pollution.

Thus, in recent years, sustainability has emerged as a major international issue for the 21st century. The search is for balance between the social, economic and environmental impacts of human activities. Sustainability in construction 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 recognition is just beginning to induce construction clients to consider the sustainability impacts of how we build, operate and maintain our buildings, as indicated by the growing use of environmental rating systems for buildings such as BREEAM (BRE, 1998), LEED (USGBC, 2001) and Ecohomes (BRE, 2000). For example, the Housing Corporation which funds much social housing in the UK now requires an Ecohomes environmental rating for all housing schemes they finance and 50 percent should achieve a rating of "Good."

UK Housing

Housing is a central feature of cities and the provision of adequate dwellings for the population is a basic goal of cities. However, in many western cities, the mass provision of housing to huge populations is increasingly leading to questions about the most appropriate and sustainable way to supply the demand for larger, higher quality housing. The technology used in housing has not developed very much over the last century, particularly when compared to changes in the automotive or electronics industries. Housing is still predominantly supplied by labor-intensive, on-site construction methods using small components, and involving little off-site manufacture.

"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).

One of the reasons for this is that, to date, prefabrication in housing in the UK has not been a commercial success. It has often been associated with a reduction in flexibility and choice for the designer, client and end user, and with higher costs. Until recently, perceived market resistance prevented significant uptake of such technology in the UK, despite examples here and from abroad illustrating its technical feasibility. In the UK, following 1945, and sponsored by successive governments, there was an organized drive for the mass provision of (mainly social) housing, using various industrial building methods such as large, panel concrete construction. Many of these projects subsequently suffered technical and social problems and in the last quarter of the 20th century, there developed considerable mistrust and a perceived market resistance towards innovative construction methods, particularly in residential construction, influenced by past errors in design and construction. The problems included inappropriate technologies which led to moisture penetration, condensation and mould 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-storey 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.

As a result, the UK housing stock is now ageing, renewal rates are slow, and supply is insufficient. Government predictions of household growth suggest that 3 million new dwellings will be required by 2016, in addition to renewal of existing stock. A construction program of between 225,000 and 250,000 homes annually is required, just to achieve housing renewal on a 100-year cycle. Yet, house building completions in recent years have fallen to their lowest level for many years with just 166,000 new homes completed in Britain in the year 2000. Completions are at their lowest since the 1920s, so current replacement rates are minimal, with most new housing adding to the stock rather than replacing old, outdated housing.

This demand for new housing presents a significant challenge to the UK housing industry. How can housing needs be met while minimizing environmental impact? The diminishing labor force, increased business performance demands, client requirements for higher building standards, health and safety issues and the industry's increasing regulatory improvements, particularly in thermal and acoustic performance, are leading the industry to reconsider off-site methods of construction and to investigate other ways of building homes. The need 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 and sustainable housing.

A further factor leading to change in the industry is the government's construction policy, which is now dominated by the report of the Construction Task Force *Rethinking Construction* (EGAN, 1998) and the subsequent report *Accelerating Change* (EGAN, 2002). These documents encourage the industry to address market demands for improved efficiency, better quality, faster construction and better cost control. This development has led to a greater interest in off-site manufacturing technologies and many house builders are currently investigating a variety of innovative ways of building dwellings. The trend began with the hotel sector, where quality and repeatability of units lend themselves to volumetric buildings. This technology is now being increasingly applied to apartments, houses and sheltered accommodation. 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.

Off-site manufacturing systems

In the UK, there are three principal approaches to the off-site manufacture of residential buildings (KEITH, MILNER and GORGOLEWSKI, 2001):

- Volumetric systems;
- Panellized systems; and,
- Hybrid (semi-volumetric) systems.

These are discussed below:

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 process has many benefits, including 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. 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 which have less internal fit-out.

Volumetric systems (fig. 1) have the disadvantage 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. The factories operate most efficiently when a large number of similar units are

Fig. 1: A volumetric housing scheme under construction in London.

made to the same dimensions. Both of these factors work to reduce flexibility in layout and design. For these reasons, most volumetric construction in the UK to-date has been in the hotel, hospital and fast food chain sectors, where repetition of units is possible. Increasingly, they are also being used for student accommodation.

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 but, in most current systems in the UK, the services installation, external cladding and internal finishing occurs on site.

Panellized systems (fig. 2) are more flexible and can more easily accommodate variations in unit plan and detail design than volumetric systems. Spaces such as bedrooms and living spaces lend themselves to panel construction systems, providing greater choice to the client and designer, with few restrictions on room size and layout. Furthermore, the advantage of panellized systems is that they 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, which it is practical to install into panels prior to shipping to site are reduced compared to the volumetric alternative. This leads to more work on site and requires further deliveries of other materials, components and labor to site. This may not be much of a problem for plain walling but would be a disadvantage for highly serviced areas, such as kitchens and bathrooms. Also, there is a greater likelihood of damage to the finishes applied to the panel during transportation or on site.

Fig. 2: Light steel frame panellized construction.

Hybrid (semi-volumetric) systems

A third option is to use volumetric units for the highly serviced areas such as kitchens and bathrooms, and construct the remainder of the building using panels or by another means. This method provides the opportunity to remove the highly serviced areas from the critical path of the project, and potentially bring together the benefits of different construction systems. It can also address the issue of providing flexibility and consumer choice.

Some schemes have used volumetric modules for bathrooms and kitchens in hot rolled steel frame or concrete frame buildings. Alternatively, volumetric units are used in combination with panels for the less serviced areas. Also, volumetric units have been used to extend buildings and provide additional accommodation with minimal disruption.

Such an approach may combine the benefits of economies of scale and the economies of scope, utilizing mass production, factory production and standardization to provide flexibility of options offering customization. A kit of parts can be used to provide flexibility yet maintain the benefits of standardization.

Sustainability benefits

How can the move towards off-site manufacture lead to sustainability benefits, and reduce the negative impacts of the additional three million homes? Below is a discussion of the potential areas of overlap.

Reduced local impacts

One of the key features of prefabrication is that much of the process is removed from the site to controlled factory conditions. This strategy reduces the amount of time spent on site, which leads to reduced 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. In the catering industry, clients have claimed a factor of ten improvements in installation and commissioning timescales for a typical fast food restaurant when using volumetric construction. For example, McDonalds burger bars are now regularly prefabricated off-site and assembled with only about 1 week of site work before opening. One example was completed with only 24 hours of work on site. This means that the locality around the site is disrupted for a shorter period reducing noise, pollution emissions and local traffic disruption. Furthermore, the lightweight nature of the buildings can often result in smaller foundations and therefore less ground work, also reducing local disruption as well as reducing the volume of materials used in the ground work. For example, steel piled foundations, and substructures can lead to considerably less removal of spoil from the site (GORGOLEWSKI, 2001).

From a financial point of view, the shorter construction period allows for a quicker return on investment by the client, and reduced overhead costs.

Reduced levels of defects

A building site does not provide an ideal environment for achieving quality construction or safety. Achieving quality construction is often very difficult in exposed site conditions. Factory-based activities allow for better quality management, and testing and checking procedures can be more easily implemented. For example, volumetric units can have electrical and water installations fully tested prior to leaving the factory. General experience in the UK suggests that far less call backs are necessary to make good defects after completion for buildings, using prefabrication. There is a significant cost and efficiency benefit to the builder and leads to satisfied customers. It also improves efficiency and reduces wastage of resources.

Less waste in manufacture

Waste from construction is one of the principal waste streams in many developed countries, in the UK leading to about 70 million tonnes of waste per annum. Manufacture in a factory allows far better management of the waste stream, with more efficient use and ordering of exact amounts of material, 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 manufacturers of components 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 co-ordinate sizes so that materials such as timber and gypsum sheets are used in their standard sizes without generating many off-cuts. Assembly of prefabricated components on site should generate little waste as the components come to site pre-engineered for easy assembly.

Health and safety benefits

Construction work on site can be a dangerous activity and leads to significant numbers of casualties and fatalities. More demanding health and safety requirements are pushing many builders to consider off-site manufacturing techniques. In this way, much of the process is carried out in more controlled and comfortable factory conditions where safety requirements can be more easily met and policed, and healthy and comfortable working conditions are more readily maintained. This approach also helps with attracting and retaining a high quality workforce, who are increasingly hesitant to work on inhospitable and often dangerous building sites. The use of scaffolding is of particular concern, and some schemes in the UK have tried to eliminate the need for scaffolding completely by integrating claddings in the factory. Conversely, the use of heavy lifting equipment to locate the prefabricated components on site requires careful management.

Improved environmental performance of the final product

Thermal and acoustic performance is dependent on the quality of workmanship and supervision. The correct installation of the elements of the fabric, in particular insulation materials and air barriers, are important to the performance of the building in use. 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. Reports from North America suggest that direct comparisons show higher thermal performance standards for homes that use off-site manufacturing techniques (CORNER and STURGES, 1995).

Social benefits from improved working conditions

Employment at a factory that manufactures 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, which necessitates greater training by employers.

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.

Greater efficiency in the use of resources, both materials and labor

Building sites are notorious in poor efficiency in the use of labor and materials. Studies in the UK estimate that up to 30 percent of construction work is done to correct poor workmanship or design. Furthermore, site labor is being managed at 40-60 percent of potential productivity, given the level of technology employed (EGAN, 1998). It is estimated that 19 percent of materials delivered to UK construction sites is wasted and never used properly (HOUSE OF COMMONS (UK), 2005).

In addition, volumetric construction using prefabricated pods or modules 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 uneconomical at their original site. Similarly, many volumetric buildings are 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 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 European legislation about producer responsibility encompasses the construction industry.

Transport

Transport is a complex issue, and monitoring of transport patterns relating to construction sites is difficult. In general, prefabrication leads to reduced numbers of deliveries to site, compared to traditional construction methods. Some monitoring of a site in London suggested that deliveries to site were reduced by up to 60 percent for a volumetric building compared to a similar building nearby using traditional construction methods (STEEL CONSTRUCTION INSTITUTE, 2000).

The wider transport implications of prefabrication are difficult to measure. There is a need to carry out meaningful comparisons of alternative prefabrication systems, such as volumetric and panellized methods, with traditional sites for transport impacts. Deliveries of large volumetric components often come from considerable distances from the factory. Location of the manufacturing facility may be critical. 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 on 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.

Moreover, the additional transport movements related to the factory should be considered. However, the workforce in a factory is more likely to be local, and thus will travel shorter distances, and is more likely to use public transport, where possible. Secondly, material deliveries to a factory can be planned so that full loads are always delivered, and local suppliers can be used.

Conclusion

There is an increasing interest in off-site manufacture in the UK house building industry. House builders are beginning to realize that there is a need to improve standards and that new regulatory requirements, such as the changes to the Planning Laws and Building Regulations dealing with energy efficiency and acoustics, will be satisfied more easily by increasing the amount of off-site manufacture. Sustainability issues are a significant driver for change.

The objectives of sustainability and the "Rethinking Construction" agenda of improving efficiency in construction overlap in several areas, notably waste minimization, process integration, a commitment to people and a quality driven agenda. Off-site manufacture offers an opportunity to address both these agendas, and improve both efficiency and sustainability. However, the industry has much to learn to fulfil the potential of this technology.

Perhaps the optimal solution requires a more locally integrated system of smaller scale manufacturing facilities that can respond to local material availability, local skills and local design requirements. Such plants could be integrated into industrial ecological systems, where wastes from one industrial process form the resources for the next. Wastes from other local industries, such as agriculture or demolition, could potentially be used in the manufacture of large-scale construction components. Such a vision, based on local need, local supplies of materials and labor, and providing products appropriate to local culture and climate, yet based on industrial efficiency, and the latest technology, has huge potential to support a move towards the more sustainable supply of housing.

References

ASHWORTH, A. and K. HOGG (2000), *Added Value in Design and Construction* (London, Longman).
BRE (1998), *BREEAM Offices 98* (Garston, UK, Building Research Establishment).
—— (2000), "Ecohomes – the environmental rating for homes" (Garston, UK, Building Research Establishment), BRE report BR 389.
BRUNDTLAND, G.H. (1994), Symposium: "Sustainable Consumption," Oslo.
CORNER, D. and W. STURGES (1995), *Experimental Student Family Housing – Technology: Design, Production and Resource Conservation,* Association of Collegiate Schools of Architecture (ACSA) Annual Meeting, Seattle, WA.
CRISP (1999), *Integrating Sustainability and Rethinking Construction* (London, Construction Research and Innovation Strategy Panel – Sustainable Construction Theme Group).
EGAN, J. (1998), *Rethinking Construction*: The Report of the Construction Task Force on the Scope of Improving the Quality and Efficiency of UK Construction (London, HMSO).
—— (2002), *Accelerating Change – A Report by the Strategic Forum for Construction* (London, Rethinking Construction). www.rethinking-construction.org.
EVELYN, J. (1661), *Fumifugium or The Inconvenience of the Air and Smoke or London Dissipated,* available in Early English Books Online.
GORGOLEWSKI, M. (2001), *The Environmental Impacts of Steel Piling* (Ascot, UK, Steel Construction Institute), publication SCI, P199.
HOUSE OF COMMONS ENVIRONMENTAL AUDIT COMMITTEE (2005), *Housing: Building a Sustainable Future,* First report of session 2004/05, vol. 1 (London, The Stationery Office).
ROSS, K., M. MILNER and M. GORGOLEWSKI (2001), *Off-site Produced Housing – A Briefing Guide for Housing Associations* (Garston, UK, Building Research Establishment).
STEEL CONSTRUCTION INSTITUTE (2000), *Value and Benefit Assessment of Modular Construction* (Ascot, UK, Steel Construction Institute).
US GREEN BUILDING COUNCIL (2001), *LEED Reference Guide* (US Green Building Council).