# INTRODUCTION OF NEW TECHNOLOGY FOR A CUSTOMER-FOCUSED SPECULATIVE HOUSEBUILDING INDUSTRY

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The UK house-building industry has often been criticized for failing to meet the housing needs of the country. The traditional craft-based build process prevalent in the UK is labour intensive with a long lead-time, and is difficult to control for product quality. It is also not suitable for configurable designs that would help to customize the home to individual needs, and the industry has been criticized for excessive standardization of its products. Attempts at industrialized housing, found in many other countries, have usually failed in the past due to lack of clear objectives and inadequate R&D. The paper presents work that is being carried out on investigation of alternative technologies. The implication of such changes for the industry – on the product introduction process, organization and culture – are discussed.

Keywords: housebuilding, industrialized housing, product introduction, customization.

## INTRODUCTION

Among major industrialized countries, the UK invests one of the lowest share of national income in housing (HBF 1998), and output for owner-occupation has been in long-term decline (Ball *et al.* 1988). Predictions of demographic changes, however, suggest the need for a reversal of this trend to cater for 4.4 million new households estimated to be formed by 2016 (DETR 1997). Most of the new stock is provided by a small number of builders offering a standard range of products for the mass market, who develop land and build homes on a speculative basis. The main operational drivers in the industry tend to be production and sales targets, rather than customer-focused objectives related to products and services. A particular problem is the diversity in demand that the speculative builders are not catering for at the moment, and the industry has been criticized for the excessive standardization and the relatively poor quality of its products (Ball 1996). Development of customer-focused operations to deliver greater product choice and quality will require many changes and, in particular, effectiveness of the current build method will need to be examined. The work reported here is part of a project that is being carried out with a major house-builder to study the changes in operations and culture needed in the industry. The paper discusses steps that are being taken to study alternative technologies and the implications of any changes.

## BUSINESS DRIVERS FOR CHANGE

The UK housing industry has for long relied on the dynamics of land and house price inflation for its profits (Barlow 1993). It faces little international competition, which has usually been the catalyst for change in other sectors. Competition is primarily

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based on price, and there is relatively little differentiation of products and services. The limited form of competition has been a barrier to the development of a customer-focused industry. The opportunity exists for a builder to gain competitive advantage by leading the process of change towards a more product-market-orientated industry. Companies in many sectors have used a variety of performance metrics as drivers to improve business processes (Slack 1991). The most relevant ones related to product strategy are cost, quality and choice offered to customers, and decisions on any new build technology will have to be based on its effect on gaining competitive advantage on these measures.

- **Cost:** Price is the main competitive factor, particularly at the entry-level end of the market. Potential cost of the product has to be carefully evaluated prior to any move towards new technology, but a direct comparison at the outset is misleading. If a new technology is applied to old house designs, then the full advantages of the new method often will not be fully realized. For example, traditionally built houses have been designed with solid timber joists, which may not be the most cost effective approach when considering an alternative build technology. Any new process has to be cost-engineered for the particular application and, in general, considerable opportunities for this should exist in the factory-build environment, whereas there is little scope for substantial re-engineering of the current, mature on-site construction method. A holistic measure of cost is also necessary, taking into account the effect on indirect site costs (e.g. of waste disposal) and that of rework which are expected to decrease with increasing use of pre-fabricated components.
- **Quality:** Some quality-related problems in house-building are difficult to eliminate with the current build method prevalent in England and Wales (brick-and-block), which relies much more on 'wet trades' than the industrialized housing common in many countries (Bottom *et al.* 1994). It is particularly affected by inclement weather, and the use of 'wet trades' produce dimensional instability which adds to the inherent inconsistencies of any craft-based process. Product quality should improve with a move towards industrialization and on-site assembly of pre-fabricated parts. Greater process control should lead to better assembly, and pre-fabrication that allows for the rapid construction of an external shell will reduce dependence on the weather. Many of the problems, however, also arise due to a culture that is tolerant of failures and, hence, a shift in attitudes is just as important as new technology.
- **Product choice:** The speculative builders, serving a volume market, offer a standard range of products defined primarily by architectural styles, type (terraced, semi-detached, detached), and the number of bedrooms which is usually fixed for a given plot size /price bracket in a locality. Production volume is achieved by offering products usually ranging from 2 to 5 bedroom homes, but the internal layout and specification are largely fixed for a given range. Customers have a limited choice of finishes. Thus, market coverage is wide but segmentation is shallow; a survey carried out as part of the wider research programme indicated that it does not cater for the different types of trade-off decisions which increasingly diverse population groups have to make (Roy and Cochrane 1999). Demand in such a market could not be matched through a speculative-build strategy alone. Instead, there is a need to adopt concepts of mass customization (Pine II 1993, Lampel and Mintzberg 1996), so as to offer much greater choice efficiently from a relatively small basic product range. The products will have to

be based on pre-designed platforms that can accommodate customer choice of internal configuration, layout and fittings. The basic range can be defined by footprints and architectural styles. Work on the non-customizable elements will need to be separated from that of customizing the product as its definition gets finalized. This will require changes in technology with the use of pre-fabricated parts, modular design and build, and new business processes to support late configuration of the product (Roy and Cochrane 1999). The approach is similar to that taken by, for example, major Japanese builders (Gann 1996). The term 'technology platform' is used in this paper to refer to the integration of different component systems in a way that enables a wide range of house designs to be produced.

## INDUSTRIALIZATION OF HOUSE BUILDING

Masonry construction method will struggle to deliver the product performance required if, as expected, insulation standards start to get stricter (Ball 1996). The craft-based approach also makes process control difficult, and the dimensional instability/ inconsistencies of the process restrict or complicate the use of pre-fabricated parts even in the interior of the house. Russel (1981) has described the history of industrialization in UK housing. Early work was on cost reduction and easing of the construction process through simplification of design and standardization of building components, e.g. doors, windows, fire gates and mantels (Swenarton 1981). With the shortage of housing after the Second World War, there was a call for standardization of models (and not just components) and the use of mass production techniques (Lyall 1995). Eleven different pre-fabricated house types were built with public money, but none in sufficient volumes for the capital costs in the factories to be amortized (Russel 1981). The thinking was pushed further in the 1960s when blocks of flats were built with government subsidy; this in part arose out of a belief that architecture was to be the instrument for social change (Russel 1981). Miles (1996) attributed the failure of such attempts to a number of factors: - there was an implicit assumption that cost would fall automatically with volume and no significant attempt at cost-engineering was made; designers were seduced by new technology instead of trying to find solutions to clearly defined social needs; the experiments did not involve significant players in the industry.

The only significant form of pre-fabricated housing currently to be found in the UK is of timber-frame construction, accounting for 40% of private houses built in Scotland in 1995 but only 3% in England and Wales (Mackay 1996). Inspection of timber-frame homes suggests longevity equivalent to those of masonry construction, but minor concerns remain about the integrity of the vapour barrier and the differential movement between the frame and the brickwork (Covington *et al.* 1995). Factory-build methods have been in use for a number of years in some European countries (Ridout 1989, Cooke and Walker 1994), Japan (Bottom *et al.* 1994, Gann 1996), North America (Russell 1991, Ryhn 1995) and elsewhere. Many builders in Japan and the USA offer wide-ranging pre-designed options and even personalized homes, particularly for up-market (steel or timber-frame) products. In Europe, less expensive examples of pre-fabrication methods include the Danish aerated concrete systems (Ball *et al.* 1988) and tunnel form concrete systems in the Netherlands (Ridout 1989). Flexibility of the build process, needed for efficient customization, has been the subject of much study under the Dutch 'open building' concept, which seeks to separate the construction of the structure of the house from its fit-out in a way that allows the latter to be personalized (Cuperus 1994). There is much that UK speculative builders can learn from these examples, but differences in applications, markets and culture have to be taken into account. Any technology that is adopted has to be engineered to the right cost for a mass market, combine significant product choice with some form of speculative build (Roy and Cochrane 1999).

Ball (1996) has argued that such industrialization has not developed in the UK due to the absence of specialist sub-contractors and adequately trained labour. However, the skills needed, although new to house-builders, are not high in relation to the country's manufacturing skill-base and, to an extent, exist in the commercial-building sector. More of a barrier to new entrants is the lack of knowledge of the market and the land-acquisition process (a key business driver in the UK). The speculative builder is in the best position to interpret the market and, although they have no manufacturing capability, they could take on the role of system integrators in the same way as is increasingly seen as the key function of vehicle and aircraft manufacturers. For this to succeed, it has to develop a systematic R&D process. Prototypes have to be built with appropriate technology platforms to evaluate the product and the build process, and identify opportunities for improvements. Methods for measuring product performance and process cost would need to be put in place. A team culture would need to develop with suppliers to engineer the product for the particular application. Connectivity of the elements of the platform needs to be studied for ease of assembly, product quality and scope for delivering product choice. Market reactions to the new technology have to be carefully evaluated. Such detailed research has often been lacking in previous attempts at industrialization (Miles 1996).

## INTRODUCTION OF NEW TECHNOLOGY

The technology platform needs to be evaluated as a whole, and must conform to the rules of engagement needed for its various elements to be interfaced effectively (Groàk 1992). Subject to such constraints and the need to meet the requirements of mortgage lenders and various statutory bodies, there are usually a number of options for each of the elements of the platform. No single set is likely to be best against all the criteria that may be used to judge it. A multi-disciplinary team with knowledge of the product, technology, site process and the market was put together from the partner company's staff to arrive at a consensual judgement on a small number of options to be studied in greater detail. Criteria used for comparison were of two types - *process criteria* affecting product quality and customization, and *specification criteria* on the way the performance of the house may be affected. The process criteria used were minimization of weather susceptibility on site; degree of pre-fabrication; minimization of on-site labour and wastage of materials; modularization and minimization of the number of components; dimensional consistency of components, effect on 'open building'/ mass customization. The specification criteria used were - maximum utilization of footprint of the house; its energy efficiency; security of the house; its maintenance; sound attenuation; aesthetic effect of the technological features; thermal stability of the house; perception by the customer of the risk associated with the technology. The aim was to select those that did best against the process criteria, but at least as well as masonry construction on the specification criteria. The list that was considered by the team is shown in Table 1, and the following general conclusions were drawn from the deliberations.

**Table 1**: Technology options considered

| | |
|---|---|
| **Structure** | |
| Masonry cavity wall | Standard brick and block construction is the conventional form of house construction in England and Wales. |
| Tunnel form | A Dutch method in which concrete is poured over steel reinforcement and within a steel former, which is heated overnight and removed the next day providing the main structure for one or two houses (Ridout 1989, Cooke and Walker 1994). |
| Volumetric steel (pods) | Steel pods are prefabricated off-site and brought in by lorry. They are normally 80-100% finished inside. The system is widely used in Japanese housing (Bottom *et al.* 1994). In the UK it is primarily used for commercial projects such as hotel blocks and fast food outlets (Chevin 1993). |
| Light gauge steel frame | This system produces a structural frame from cold rolled galvanized steel sections that are made into panels that are bolted together on site (Lyall 1996). |
| Timber frame | This system comes from the USA, where it is primarily stick built. In the UK it comes as panels which are joined on site. It replaces the block work in a conventional house (Lyall 1996). |
| Gasbeton | A Danish aerated concrete panel system. The panels are a storey high and 600mm wide. They are jointed with adhesive and replace the block work on a conventional house (Cooke and Walker 1994). |
| CPB/foam structural sandwich panels | A relatively new innovation in which the panels consist of two sheets of cement particleboard with an injected core of polyurethane foam. They are a storey high and 1200mm wide, and are fixed together on site with camlocks or steel straps. They replace the block work in conventional houses (Marshalls 1996). |
| KEPS | A French system made up of polystyrene blocks in-filled with mass poured concrete (Springvale 1994). |
| **Roof** | |
| Gang nail truss | Gang nail trusses are the standard UK method of roofing when access to the roof space is not required. |
| Cut purlin | This is the traditional UK roofing method, which allows access to the roof space. |
| Hybrid purlin truss | This is a Dutch system, which uses roof panels that either lie on purlins or incorporate purlins to form the roof. The panels contain insulation (Ridout 1989, Cooke and Walker 1994). |
| Steel truss | These are similar to timber cut purlin roofs and are available with steel systems or can be incorporated in other systems such as masonry construction. |
| Internal walls | |
| Timber stud drylining | This is the standard method in volume built new homes in the UK. A frame is stick built on site and plasterboard is attached to the frame. |
| Steel stud drylining | This is similar to timber stud partitioning except it is made in steel. |
| Plasterboard/ flax drylining sandwich panel | This is a Dutch system that consists of 600mm flax panels, each a storey high and with plasterboard on both sides (Opstalan 1996). |
| Gypsum blocks | A Dutch system in which solid gypsum blocks are assembled on site and held together with a plaster paste. The finished wall is then skimmed (Gibo 1996). |
| **Joists** | |
| Standard timber joists | Softwood joist. |
| Composite timber "I" beams | These consist of either steel or composite timber web and soft wood or laminated timber flanges. They minimize shrinkage, are lighter to handle and will span further than conventional joists (Milner 1996) |
| Steel joists | These are normally large C or I section steel joists. |
| Concrete | These are normally associated with concrete floors. |

- **Structure:** Volumetric production was viewed as a strong contender. In the UK this type of technology has been used in commercial applications where minimization of the on-site lead-time is considered critical (Chevin 1993). However, high cost currently rules it out as an option for the housing market; considerable re-engineering of the product and investment in new manufacturing processes will be needed to bring the cost down to an acceptable level. Tunnel form structures were considered too inflexible to provide variations to house design. Timber frame, although generally superior to masonry, was not viewed as being able to give the accuracy required for easy assembly of subsequent components. Two competing options remain – structural sandwich panels and steel frame. Compared to masonry cavity wall, both methods perform very well, particularly for their lack of susceptibility to poor weather conditions and for dimensional integrity that eases subsequent assembly operations.
- **Roof:** If the roof space is not going to be utilized, the gang nail truss was considered the most cost effective. Where a roof space is to be used, the traditional method has been the cut purlin roof. However, cheaper alternatives may be found in the hybrid purlin roof, for a long time used in the Netherlands, that places insulation in a structural panel, resulting in greater pre-fabrication and speed of construction.
- **Internal Walls:** The internal sandwich panel**s** were considered best against all the process criteria and better than current timber stud dry-lining techniques against all the specification criteria. Their use also opens up the option of further pre-fabrication through pre-wiring (possibly using plug-together connectors, similar to those used in shop-fittings) and (plastic) pre-plumbing. Currently a cheaper alternative that still delivers many of these benefits would be steel stud partitioning.
- **Joists:** If steel frame is to be used this will dictate that the joists must be in steel, but for the structural panels other options that exist are concrete floors, composite timber “I” beams and standard timber joists. Standard timber joists lack the spans that enable ‘open building’ and are susceptible to shrinkage. Concrete floors do not have these problems but are expensive and lack flexibility for installation of services. The composite timber “I” beams give good all round performance cost effectively.
- A prototype-build programme has been started with the partner company, initially to study the structure, joists and internal walling. The first was built with cement-particleboard/ foam structural sandwich-panels, composite timber “I” beam joists and steel stud partitions. A conventional gang nail truss roof was used. A weather-tight shell was erected in six days (from slab) compared to the 5 weeks it usually takes with masonry construction. However, there is significant scope for re-engineering the product/ process. The basic design can be rationalized to simplify the assembly of the panels. Unnecessary complications arose from placing the joists on top of the ground floor panels, which resulted in a need to fill the gaps between the joists with panel sections hand-cut on site. Through discussions with the suppliers it was established that the joists could be hung instead, which would save three man-days of work. It is also possible to consider rationalizing the way other elements of the house connect with the panels e.g. the windows. A new window acceptor was found, which consisted of a one-piece uPVC sub-frame that could be fixed to the panels as the wall was being erected. Once the wall was

completed, the sealed window unit could be inserted from the inside by the team erecting the panels. There were also examples of unnecessary tasks, e.g. when the ground floor panels were erected they were tied to the solid concrete slab using ties designed for use with beam-and-block floors, which are both expensive and unnecessary. The accuracy with which the panels can be erected highlighted the need to improve the way in which the channel that takes the panels is fixed and levelled. In future the panels, instead of being cut on-site, will come as a kit of parts. A new method for propping, using adjustable steel props instead of timber, should ensure that the panels remain plumb while the floor and roof are assembled; new corner panels are also to be used. The combination of all these and other recommendations should result in the panels for a standard house to be erected in less than two days by a team of three. The house was fully tested for acoustics, air tightness and effectiveness of insulation, and the buyer has been interviewed quarterly to assess customer reaction. The results are confidential and their implications need further study but, compared to that for a control house of the same design built using conventional methods, showed equivalent or improved performance.

The second prototype was of (platform) steel-frame. Steel was used for both structural and non-structural walls and the joists. A weather-tight shell was completed in 5 days. Again scope for rationalization was identified, e.g. in the floor design which required as many as 1200 screws to fix the joists and the decking. Of the 152 man-hours (four days) taken to erect the steel frame, 58 man-hours (approximately 1.5 days) were taken on the first floor; this could be made significantly less if joists capable of spanning a much longer distance than the present 4.5m were developed. This would reduce considerably the number of fasteners required and remove the need to use hot rolled steel, an expensive feature of this house type. Another advantage of a long-span joist is that it enables the open-building concept to be followed more fully, improving the ability to customize the house. A problem for installation of services was also identified. Both the plumber and the electrician had to drill their own holes, and found it both difficult and time consuming. This is an example of the need to consider the follow-on trades when adopting new processes. The steel-frame supplier agreed to swage punched holes to remove the need for grommets when adding in the services; the position of the holes were to be designed to maximize the scope for variation on services-runs and enable additional electrical sockets to be added at customer request. Results of performance tests again compared favourably with that for a house built using traditional methods.

The recommendations were communicated to the suppliers through extensive briefing sessions. Another prototype of the steel-frame house was built with many of the changes incorporated. The joists were of the same depth as before but able to span a minimum of 6m, and consisted of an open-lattice structure with no sharp edges, thus avoiding the need to protect either wiring or plastic plumbing. However, they took longer to fix than expected due to problems with the new joist-brackets. These have now been solved, and it should be possible in the future to erect the frame in 3 days (104 man-hours). For the installation of services, very few additional holes were required; this saved the plumber a day’s work and first-fix wiring was completed in 4 hours using a wiring harness. The steel-frame supplier is working on proposals to eliminate the need for drilling these additional service-holes, and investigating the possibility of supplying wall-length panels to reduce further the on-site assembly time.

Two further build methods have been studied– stick-built steel-frame and a new panel system. Steel-frame construction method has been in existence for some time now and is extensively used world-wide, but a panel system provides an alternative which, in the longer-term, may prove to be a more complete solution, particularly when considered in conjunction with other elements of the house. Options for these will be considered once the studies on structures are complete - e.g. foundation (traditional, pre-formed); cladding (brick, brick slips, ceramics); services (traditional, modular, integrated); in-fill (traditional, factory-made, sub-assemblies). Methods for customization will need to be studied, and assembly methods defined to obtain the best finish quality (e.g. use of fasteners, adhesives).

**Culture and organizational changes**

The builder will also need to examine its core competencies and role. Traditionally the skills have been in land acquisition, sales and project management of site-work. The industry has tended to contract out the construction work as a way of reducing cost in a volatile market, which has led to a reduction in training opportunities (Ball 1996). A move towards industrialized housing will bring more supply-and-fix contracts but, to ensure quality of the finished product and its rapid configuration to customer choice, the builder may also need a core assembly team of highly-trained, directly-employed operatives, primarily for fitting-out the house. Many builders have also contracted out much of the work on product engineering which, in any case, has been viewed primarily in terms of functionality (often legislation driven), aesthetics and structural properties of the product. Concepts of design for assembly have received relatively little attention. If it were to become a system integrator for industrialized housing, the builder would need expertise in process engineering to be able to engage effectively with suppliers.

The prototype-build programme has demonstrated the importance of teamworking for product development, a departure from the adversarial relationship that is typically found in the supply chain of the construction sector. A change in attitude will also be needed in all stages of product supply if the goal of a customer-focused organization is to be achieved. Failures in product quality itself cannot be simply attributed to the current build process, and just as much importance must be placed on a change in culture as on the introduction of any new technology. A Total Quality Management initiative has been developed as part of the overall research project, and is gradually being implemented within the partner company. It is designed to get a wide cross-section of people involved in the programme and setting of process-improvement targets. Customer-satisfaction and process-fault monitoring systems have been introduced to identify priority areas for improvement. A Quality Action Team approach, modelled on that used by a car company, was implemented as one of the first steps in the introduction of teamworking for process analysis and continuous improvement. Quality Councils have been established in each operating region with the responsibility for sponsoring cross-functional teams to find solutions and eliminate root causes of problems in the priority areas identified. Suppliers and sub-contractors will also need to be involved in the initiative if a true culture change is to be achieved. Some initial steps on this have been taken, but any supplier-development programme will only be credible once the house-builder itself has shown visible signs of change.

## CONCLUSIONS

The UK house-building industry has been falling behind its counterparts in Europe, North America, Japan and elsewhere in terms of innovation and product quality, and a recent report has highlighted the need to reverse this trend (Egan 1998). The prevalent craft-oriented build process is ill-serving its customers and the housing needs of the country. Clearly this must contribute to the instability in the housing market that has been observed by many (e.g. Clapham 1996). Skill shortages, often the driving force for change, will also make it necessary to re-examine the build process. The paper has presented work that is being carried out to investigate options for change. Examples of industrialized housing can be found in many countries, which have benefited from improved product quality and the availability of much greater choice to suit individual needs. Past attempts at similar innovation in the UK have failed due to lack of clear objectives and sufficient attention to the requirements for such an initiative to succeed. Considerable R&D is needed to ensure that the product cost is right for the market, and the process is efficient, produces quality products and enables a high degree of customization in a speculative-build environment. The adversarial relationship prevalent within the supply chain of the industry has to be replaced by a partnership culture, and the builder has to take on the role of a system integrator.

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